March 1994

IDENTIFICATION OF THE SPAWNING, REARING AND MIGRATORY REQUIREMENTS OF FALL CHINOOK SALMON IN THE COLUMBIA RIVER BASIN ANNUAL REPORT 1992

Annual Report 1992

DOE/BP-21708-2

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This report was funded by the Bonneville Power Administration (BPA), U.S. Department of Energy, as part of BPA's program to protect, mitigate, and enhance fish and wildlife affected by the development and operation of hydroelectric facilities on the Columbia River and its tributaries. The views of this report are the author's and do r necessarily represent the views of BPA.

This document should be cited as follows:

Rondorf,Dennis W. National Biological Survey Columbia River Research Laboratory, William H. Miller U.S. Fish and Wildlife Service Idaho Fishery Resource Office, U.S. Department of Energy, Bonneville Power Administration, Division of Fish and Wildlife, Project Number1992-029, Contract NumberDE-AI79-9 1 BP2 1708, 229 electronic pages (BPA Report DOE/BP-21708-2)

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IDENTIFICATION OF THE SPAWNING, REARING AND MIGRATORY REQUIREMENTS OF FALL CHINOOK SALMON IN THE COLUMBIA RIVER BASIN

ANNUAL REPORT 1992

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Project Number92-029
Contract Number DE-AI79-9 1 BP2 1708

MARCH 1994

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EXECUTIVE SUMMARY

This document is the 1992 annual progress report for selected studies of fall chinook salmon Oncorhynchus *fshawytscha* conducted by the National Biological Survey (NBS) and the U.S. Fish and Wildlife Service. Activities were funded by the Bonneville Power Administration (BPA) through funding of Project 92-029.

The decline in abundance of fall chinook salmon in the Snake River basin has become a growing concern. In April 1992, Snake River fall chinook salmon were listed as "threatened" under the Endangered Species Act. Effective recovery efforts for fall chinook salmon cannot be developed until we increase our knowledge of the factors that are limiting the various life history stages. This study attempts to identify those physical and biological factors which influence spawning of fall chinook salmon in the free-flowing Snake River and their rearing and seaward migration through Columbia River basin reservoirs.

Aerial surveys to count fall chinook salmon redds in the Snake River have been made annually since 1987. These flights are index flights and are useful for historical comparison. Index counts of Snake River fall chinook salmon redds increased from 32 in 1991 to 40 in 1992, but were still lower than the 1987 high of 66. We began making weekly flights in 1991 to increase the accuracy of redd counts. The 1992 weekly count totalled 45 compared to the 1991 weekly count total of 41. We also began underwater surveys in 1991 to search for redds in deeper water. There was no conclusive evidence of deepwater spawning found in the free-flowing Snake River or below Lower Monumental Dam in 1992, but the area covered was relatively small and limited to know spawning sites.

The flow and temperature regimes of the Snake River were studied to assess the effects of the Hells Canyon Dam on fall chinook salmon spawning and early life history. We found that Hells Canyon Dam shaped the flow pattern of the Snake River downstream to RK 270. The thermal regime of the Snake River was colder during egg incubation and fry emergence during the 1992 brood year than during 1991. Our calibrated hydraulic model of RK 261 predicted that the flow required to dewater the shallowest fall chinook redds at RK 261 would be 7.4 KCFS (gaged at RK 2701, which is well below any actual flow event which occurred during fall chinook salmon spawning or egg incubation of 1991 or 1992. Consequently, the ongoing attempt by the Idaho Power Company to prevent fall chinook salmon redd dewatering by stabilizing flows from Hells Canyon Dam throughout spawning had positive effects in 1992.

Migratory behavior of subyearling fall chinook salmon was examined in laboratory swimming performance tests. Subyearling chinook salmon were displaced most rapidly during May and June in a swim flume when they were less than 9 cm in length and the water temperature was less than 16°C. During displacement the fish swam upstream at about the optimum velocity of 1 bl/s, or just fast enough to maintain body control. During the peak of emigration, fish are capable of moving substantial distances during the day as well as at night, the time when they usually are displaced the farthest. Fish actively swam downstream only at very low water velocities, when their disposition to migrate was maximum, and rarely drifted in the current.

The use of PIT tags in subyearling fall chinook salmon was evaluated in laboratory tests. In 44-d rearing trials conducted during 1992 mortality due to PIT tagging was l%, a reduction from delayed mortality ranging from 7 to 27% during 1991. Mortality was reduced in 1992 by using an improved tag insertion technique, increasing the minimum size to 60 mm, and the use of a buffered anesthetic with shorter exposure times. Consequently, predation vulnerability was reduced in fish allowed 0.5 h recovery after PIT tagging in 1992 tests as compared to 1991 tests. Predation of PIT-tagged fish by smallmouth bass *Micropterus dolomieui* was not size selective. A comparison of U-critical swimming speed of PIT-tagged and control fish allowed to recover for time periods ranging from 0.5 h to 96 h indicated that effects from tagging on swimming performance could be as long as 24 h.

Juvenile fall chinook salmon were seined and PIT tagged in the free-flowing Snake River to describe rearing patterns, emigration behavior, and emigration timing. We seined 1,309 fall chinook salmon in systematic samples in 1992. Estimated fall chinook salmon fry emergence ranged from 18 March to 25 May with a 25 April peak. We PIT tagged and released 1,100 chinook salmon juveniles of which 947 were considered as fall chinook salmon (87%) on the basis of post season race separation. We tagged fall chinook salmon in the Snake River from 14 April through 10 June with a 27 May peak. About 7% of all tagged fall chinook salmon were recaptured by seine; most at the original site of tagging. Mean emigration rate from release sites in Hells Canyon to Lower Granite Dam was 3.6 km/d with peak and median dates of passage occurring on 23 and 22 June, respectively. Using multilinear regression we estimated that emigration rate was significantly influenced by temperature, flow, and fish size.

Juvenile fall chinook salmon were seined in the Columbia River in the Hanford Reach and in McNary Reservoir to identify and describe rearing habitats of naturally produced fish. Peak numbers of subyearling chinook salmon were captured during May in all reaches, but as water temperatures increased above 15.9°C, mean catch decreased. Columbia River subyearling chinook salmon emerged earlier and remained smaller than Snake River subyearlings. Subyearlings were caught in significantly greater numbers during the day than during the night. Most subyearlings were caught in shallow water between 0.5 m and 2.0 m deep. Substrate did not appear to have an influence on catch of subyearling chinook salmon in the main stem Columbia River.

Subyearling fall chinook salmon were marked at McNary Dam to relate river flow and migration patterns of juvenile salmon to adult returns. A total of 105,250 fish emigrating during the early, middle, and late segments of the migration were successfully coded wire tagged and released at McNary Dam. Delayed mortality and tag loss ranged from 0.6 to 0.7% and was considered acceptable. Adequate numbers of branded fish were recaptured at John Day and Bonneville dams to determine that the three groups of fish maintained their integrity and emigrated separately in relation to when they were released. Travel time of subyearling chinook salmon through John Day Reservoir was not significantly correlated with any of the variables tested. Subyearling chinook salmon marked at McNary Dam appeared to be fully smolted and were physiologically adapted to seawater as measured in 24 h seawater challenges. Gill ATPase activity declined toward the latter portion of the emigration in control fish but remained elevated in seawater challenged fish.

ACKNOWLEDGEMENTS

We thank individuals in the Idaho Department of Fish and Game, Idaho Power Company, U.S. Fish and Wildlife Service, Washington Department of Fisheries, Washington Department of Wildlife, U.S. Army Corps of Engineers, National Marine Fisheries Service, and the Fish Passage Center that assisted with the project activities. We extend special thanks to our colleagues at the Columbia River Research Laboratory of the National Biological Survey and the Idaho Fishery Resource Office of the U.S. Fish and Wildlife Service for their assistance. We gratefully acknowledge reviewers for the valuable comments and suggestions which we have incorporated into this report. We appreciate the assistance of Debbie Watkins, Project Manager, Bonneville Power Administration.

CHAPTER ONE

Fall Chinook Salmon Spawning Ground Surveys in the Snake River

by

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Introduction

The number of fall chinook salmon *Oncorhynchus tshawytscha* spawning in the free-flowing reach of the Snake River declined dramatically over the past two decades (Irving and Bjornn 1981; Witty 1988; Seidel et al. 1988; Bugert et al. 1989, 1990). As a result, in 1992, Snake River fall chinook salmon were added to the federal list of threatened species (NMFS 1992). This listing increased the need for data on Snake River fall chinook salmon spawning escapement and habitat.

Our 1992 work was a continuation of research we began in 1991 (Connor et al. 1993). Our objectives in 1992 were to: (1) describe the distribution of fall chinook salmon redds in the Snake River; (2) use underwater and ground searches at study sites to improve the accuracy of aerial redd counts; and (3) assess fall chinook spawning in the tailrace of Lower Monumental Dam.

Study Area

The study area included the Snake River from Hells Canyon Dam to its mouth (Figure 1). We describe specific locations within the area in terms of river kilometers (RK) based on U.S. Army Corps of Engineers (COE) navigation charts of the Snake River (COE 1990) and U.S. Geological Survey topographical maps. Much of our work in 1992 was done in the free-flowing reach of the Snake River between Hells Canyon Dam (RK 398) and the head of Lower Granite Reservoir near Asotin, Washington (RK 235). Additional work was conducted within 1 km downstream of Lower Monumental Dam (RK 67).

Methods

Data Collection

Redd counts.-Fall chinook salmon redd count data were collected by helicopter from 1987-1992 (Seidel et al. 1988, Bugert et al. 1989, 1990, 1991, Bugert 1991, and Mendel et al. 1992). From 1987-1989, aerial counts of fall chinook salmon redds were made about the second and fourth weeks of November. In 1990, based on an interagency consensus, we added a third count in early December to check for late fall chinook salmon spawning activity. These aerial counts are useful for historical comparison and are referred to hereafter as "index counts". Each index count covered the river from Asotin, Washington (RK 235) to Hells Canyon Dam (RK 398), unless the weather became inclement. The river was scanned for fall chinook salmon redds by observers while the helicopter flew at an altitude of 100 to 200 m. When

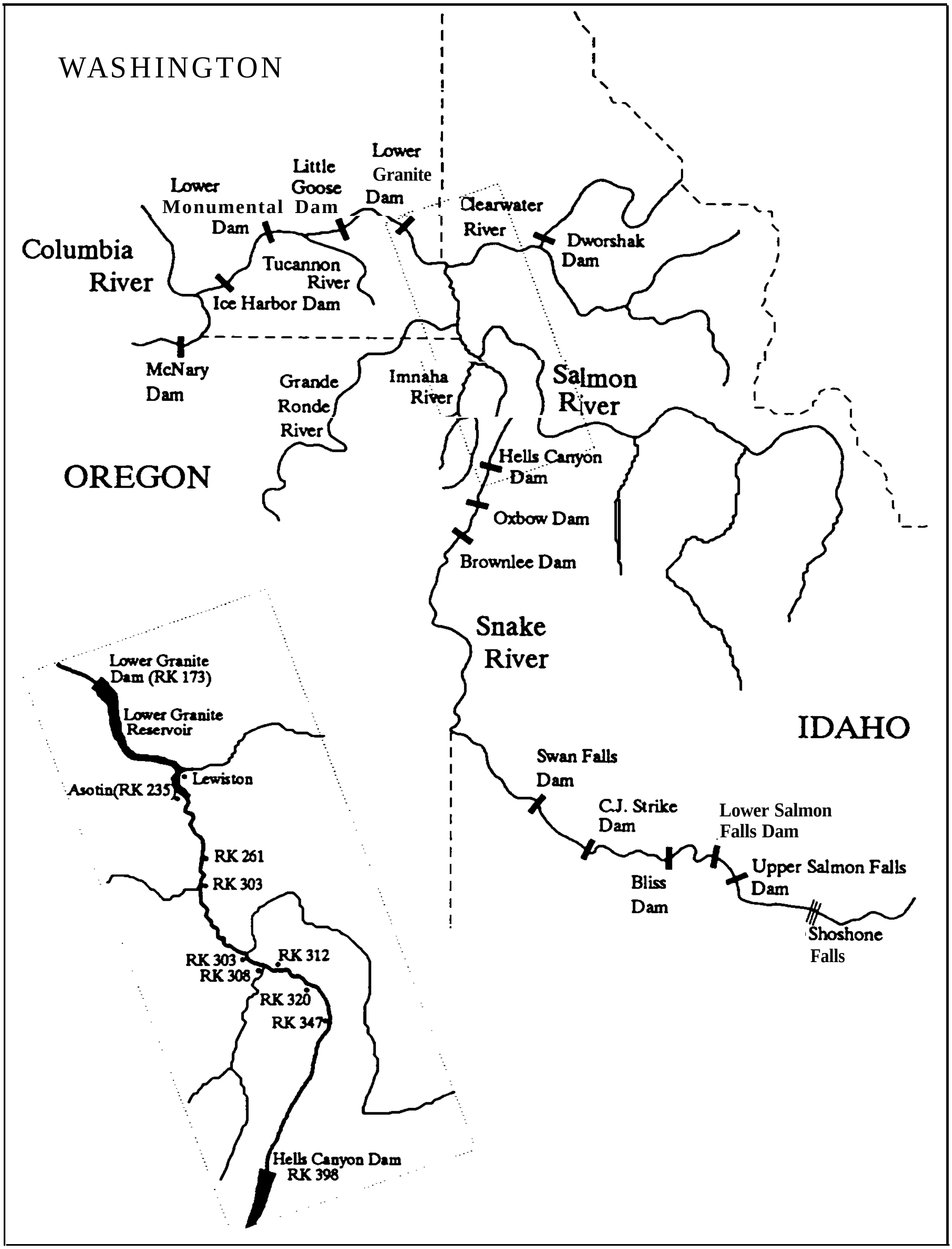

Figure l.-Map of the Snake River drainage showing Lower Monumental Dam at RK 67, and mset showing fall chinook salmon spawning study sites at RK 261, **RK** 312, and **RK** 320, and Lower Granite Dam at RK 173, and the head of Lower Granite Reservoir near Asotin, Washington at RK 235.

a potential redd was located, the pilot positioned the helicopter for optimal viewing and an observer noted the location of the potential redd on COE navigation charts. The authenticity of potential redds observed during index counts was judged from the air.

Refinements in redd counts.-In addition to index counts, "weekly" counts of new redds were made by aerial survey in 1991 and 1992, to improve count accuracy and define the timing of fall chinook salmon redd construction. In 1991, 9 counts of new redds were made by aerial surveys at 6 d to 8 d intervals from 14 October to 9 December. In 1992, 8 counts were made at 6 d to 11 d intervals from 16 October to 12 December. Weekly redd counts were made on the same flights that index counts were made on, but weekly counts were adjusted based on ground verification.

In 1992, all potential fall chinook salmon redds observed during aerial surveys were authenticated by ground truthing. Ground truthing involved viewing each redd from a position upstream and to the side of the suspected redd. The authenticity of each redd was determined based on the dimensions of the disturbed area, substrate composition, water velocity, presence of adult salmon, and the use of the area by spawning fall chinook salmon in previous years.

Underwater searches for fall chinook salmon redds were conducted in water too deep for air or ground detection. In 1991, RK 261 was the only site searched (Connor et al. 1993). In 1992, searches were made at RK 261, RK 312, and RK 320. The locations of shallow-water redds at these sites were recorded by a surveyor sighting a hand-held prism positioned over the redds by wading or boat. Buoys were then used to mark the mid-channel edge of the shallow water-redds and to establish navigation lanes in deeper water parallel to the flow. Underwater searches were made along the navigation lanes by towing a sled operated by two divers equipped with SCUBA. The divers searched for redds as they were towed upstream by the boat. The first pass at each site was run parallel to the buoys positioned near the edge of shallow-water redds; subsequent passes were initiated progressively toward mid channel. Divers scanned the river bed for redds and radioed the boat crew when redds were observed. The boat crew relayed the redd observation to a surveyor who sighted the position of a pontoon equipped with a prism array that was towed directly above the divers.

Surveys in the Lower Monumental Dam tailrace.-Substrate data were collected using an underwater camera in the tailrace of Lower Monumental Dam in mid November, 1992. The camera was attached to a 28 kg sounding weight which was lowered from a boat to an elevation about 60 cm above the bottom. The substrate was observed by surface monitor and recorded on video tape. Video observation locations were tracked by surveying a prism mounted on the boat directly above the camera. Once a video record was obtained at a location, the camera was raised and the boat moved to a new location and the process repeated. Dominant and subdominant substrate particle sizes were estimated on a video monitor using a modified Brusven index and a calibrated measuring tape (Brusven 1977; Table 1); percent fines were not estimated from video records. Dominant substrate size ranges were mapped to show the general substrate composition within the surveyed area.

Table I.-Substrate code, description, and size range used to estimate substrate composition in the Snake River (modified from Brusven 1977).

Code	Description	Size Ranse	
		inches	cm[a]
0	Fines	≤.25	≤.65
1	Small Gravel	.25-1	.65-2.5
2	Medium Gravel	l-2	2.5-5.0
3	Large Gravel	2-3	5.0-7.5
4	Small Cobble	3-6	7.5-15-o
5	Medium Cobble	6-9	15.0-23-O
6	Large Cobble	9-12	23-O-30.5
7	Small Boulder	12-24	30-S-61.0
8	Large Boulder	>24	>61.0
9	Bedrock		

[a] Metric size ranges are converted from english units and rounded to the nearest 0.5 cm.

Underwater redd searches and additional substrate surveys were made in the tailrace of Lower Monumental Dam on 17 and 18 November to test the effectiveness of SCUBA diving while water was being released through Lower Monumental Dam turbines. The underwater search methods used in these November dives were similar to those we used in the free-flowing Snake River and described previously.

A second search of the Lower Monumental Dam tailrace was made on 16 December under static ("zero-flow") conditions. Methods used for diving under zero-flow conditions were different than those used when the dam was releasing water. The boundary of the selected area was marked with four surface floats to form a rectangle with two sides roughly parallel with the shoreline. Ropes were attached between the upstream and downstream float anchors on two sides of the rectangle to form two submerged lines parallel with the shoreline. Two divers searched for redds along transects 2 m apart as they swam side-by-side above the river bed until they reached the submerged rope on the opposite side of the rectangle. Progress along the submerged ropes was marked and recorded by surveying a prism positioned over the submerged ropes by boat each time the divers moved to a new starting location. In addition, the general path of the divers was tracked while swimming between the submerged ropes by surveying a prism positioned over the diver's exhaled bubbles. Divers maintained contact with the surface crew using voice-activated radios.

Data Analysis

Redd counts.-Data from air, ground, and underwater surveys are summed to show fall chinook salmon redd counts by year, day, and RK from 1987-1992. We used the first two index counts of each year to compare redd counts between years.

Refinements in redd counts.-Redd construction timing was analyzed from weekly redd counts and compared to index counts from 1991 and 1992. In addition, we compared the results of aerial counts, ground truthing, and underwater observations at RK 261 to evaluate the effectiveness of each technique.

Surveys in the Lower Monumental Dam tailrace.-We mapped the substrate composition of areas searched by camera and SCUBA divers in the tailrace of Lower Monumental Dam to show areas containing substrate that is potentially suitable for spawning.

Results

Redd Counts (I 987-l 992)

The first two index counts in 1992 totalled 39 and one additional redd was counted on the third index count for a total of 40 redds (Table 2). Thirty two redds were counted during the three index counts of 1991 (Table 2). The sum of the first two index counts collected between 11 November and 1 December, 1987-1991 ranged from 66 to 31 (Figure 2).

Since 1987, redds have been observed from RK 240.5 to RK 396.6 (Table 2, Figure 3). In 1992, redds were distributed between RK 245 and RK 353 (Table 3). Based on all three index counts, 70% of the redds counted in the Hells Canyon reach in 1992 were located downstream of the Grande Ronde River (RK 271). The largest concentration of redds above the Grande Ronde River was 6 redds near RK 312. The largest concentrations of redds below the Grande Ronde River were 7 redds near RK 245, 7 redds at RK 259, and 9 redds at RK 261.3.

Table 2.–River kilometer (RK), landmark, and fall chinook salmon redd index counts from the Snake River, 1987-1992 (from Seidel et al. 1988; Bugert et al. 1989, 1990, 1991; USFWS files).

RK	Landmark	1987 09-Nov	1987 23-Nov	1988 14-Nov	1988 01-Dee	1989 13-Nov	1989 27-Nov	1990 12-Nov	1990 26-Nov	1990 11-Dee	1991 11-Nov	1991 26-Nov	1991 09-Dec	1992 13-Nov	1992 23-Nov	1992 12-Dec	Site Total
240.5	Ten Mile Rapids	-			-		1	1	-	-	1	-	-	-	-	-	3
244.4	Ten Mile Canyon	-			1		1	-	-	-	-	-	-	-	-	-	2
245.2	Big Bench Point	-	13	4	4	20	3	8	4	4	-	-	-	1	6	-	67
252.6	Uarehouse at Couse Crk	-			-		1	-	1	-	-	-	-	-	-	-	2
257.1	Lower Buffalo Range	-			-		-	-	-	-	-	-	-	2	1	-	3
258.9	Below Upper Buffalo	-			-		-	-	-	-	-	-	-	1	-	-	1
259.0	Upper Buffalo Rapids	-			-		-	-	-	-	-	-	-	6	1	-	7
261.3	Captain Johns Creek	-			-	1	-	-	2	-	11	3	-	5	4	-	26
262.6	Captain John Rapids	-	3		2		-	2	-	-	-	-	-	-	-	-	7
265.0	Billy Creek Rapids	2		5	-	1	1	-	-	1	-	-	-	-	-	-	10
266.0	Fisher Gulch	-	4		-		-	-	-	-	-	-	-	-	-	-	4
266.6	Upper Billy Creek Rapid	-	2	10	4		-	-	-	-	-	-	-	-	1	-	17
268.1	Louer Lewis Rapids	-			-		-	-	-	-	-	3	-	-	-	-	3
272.7	Near Leuis Point	-			-	1	-	-	-	-	-	-	-	-	-	-	1
277.6	Deer Head Rapids	-	1		-		-	-	-	-	-	-	-	-	-	-	1
279.8	Below Shovel Creek	-	1		-		-	-	-	-	-	-	-	-	-	-	1
287.9	Cochran Island Mead	-			-	1	-	-	-	-	-	-	-	-	-	-	1
307.3	Eureka Bar	-	1	1	4		-	2	-	-	1	2	-	-	-	1	12
308.4	Near Imnaha River	-	2		4		-	-	-	-	-	-	-	-	-	-	6
311.0	Above Divide Creek	4			-	5	-	-	2	-	-	-	-	-	-	-	11
311.7	Divide to Zig Zag	-			-		-	-	3	-	-	-	-	5	1	-	9
312.3	Above Zig Zag Creek	-	2		2		-	-	2	-	-	-	-	-	-	-	6
315.7	Below Dug Bar, OR	1			3		-	-	-	-	-	-	-	-	-	-	4
319.9	Above Robinson Gulch	-	1		-		-	2	-	-	-	4	-	-	3	-	10
320.0	Below Deep Creek	4			-	3	-	-	-	-	-	-	-	-	-	-	7
328.4	Near Blankenship Ranch	-	1		-		-	-	-	-	-	-	-	-	-	-	1
330.2	Above Copper Creek	-			-		-	-	-	-	-	2	1	-	-	-	3
330.8	Below Getta Creek	-	1		-		-	-	-	-	-	-	-	-	-	-	1
332.1	Below High Range No.1	1		3	1		-	-	-	-	1	-	-	1	1	-	8
334.4	Near Lookout Creek Range	-		-	1		-	-	-	-	-	-	-	-	-	-	1
334.5	Below Lookout Creek	-		2	-	1	-	-	-	-	-	-	-	-	-	-	3
337.4	Below Camp Creek	-	1	-	-		-	-	-	-	-	-	-	-	-	-	1
343.7	Pleasant Valley Creek	-		-	-		2	-	1	-	-	-	-	-	-	-	3
345.5	Near Pittsburg Range	2		-	-		-	-	-	-	-	-	-	-	-	-	2
350.4	Durham Rapids	-		-	-	1	-	-	-	-	-	-	-	-	-	-	1
351.1	Below Cat Gulch	1		-	-		-	-	-	-	-	-	-	-	-	-	1
352.9	Kirby Range	-		2	-		-	-	-	-	-	-	-	-	-	-	2
358.5	Near Suicide Rock	3			-	4	-	-	-	-	-	-	-	-	-	-	7

Table 2. (Continued).

RK	Landmark	1987		1988		1989		1990			1991			1992			Site
		09-Nov	23-Nov	14-Nov	01-Dee	13-Nov	27-Nov	12-Nov	26-Nov	11-Dee	11-Nov	26-Nov	09-Dec	13-Nov	23-Nov	12-Dec	Total
359.9	Below Temperance Creek			-	1												1
379.6	Near Hat Creek Mouth	4	-	-	2	3	-										9
379.9	Below Saddle Creek		1	-	-	1	-										2
380.9	Below Dry Gulch	1	-	-	-												1
383.6	Above Three Creek Rapids	2	-	-	-	2	-										4
387.1	Near Rocky Bar Camp	6	-	-	-	3	-					3	-	-	-	-	12
391.5	Above Warm Springs Camp		1	-	-	1	-										2
393.6	Below Brush Creek	-	-	-	-	1	-		2	-	-	-	-	-	-	-	3
396.6	Near Rocky Point	-	-	-	1												1
	Totals	66		57		58			37			32[a]			40[b]		290

[a]In 1991, 9 redds were observed during ueekly flights that were not included in index counts, and 5 redds uere observed by SCUBA divers at RK 261.3 on 26 November that were not observed by air.

[b]In 1992 an additional 6 redds uere observed but not considered redds during the 23 November index count, then validated by ground truthing: 2 at RK 266.6, 2 at RK 344.0, 1 at RK 349.6, and 1 at RK 352.9; In addition, 2 redds uere first observed then validated by boat at RK 261.3 after 12-December 92.

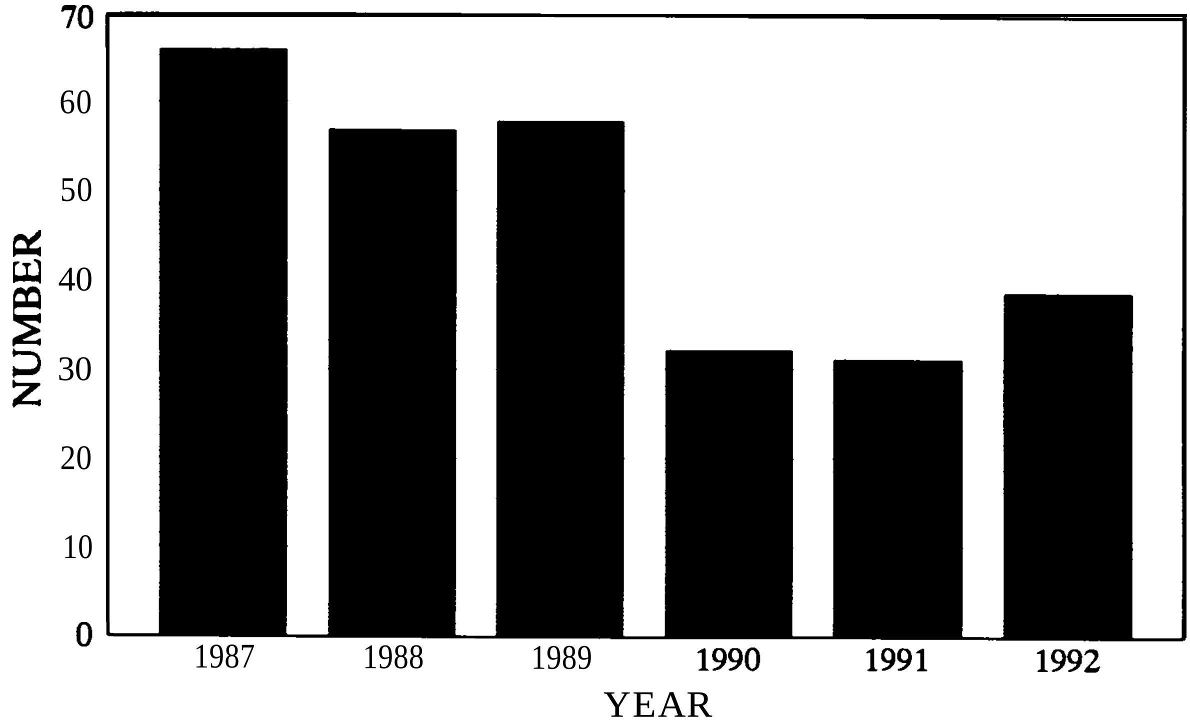

Figure 2.-Index counts of fall chinook salmon redds collected between 11 November and 1 December, 1987-1992.

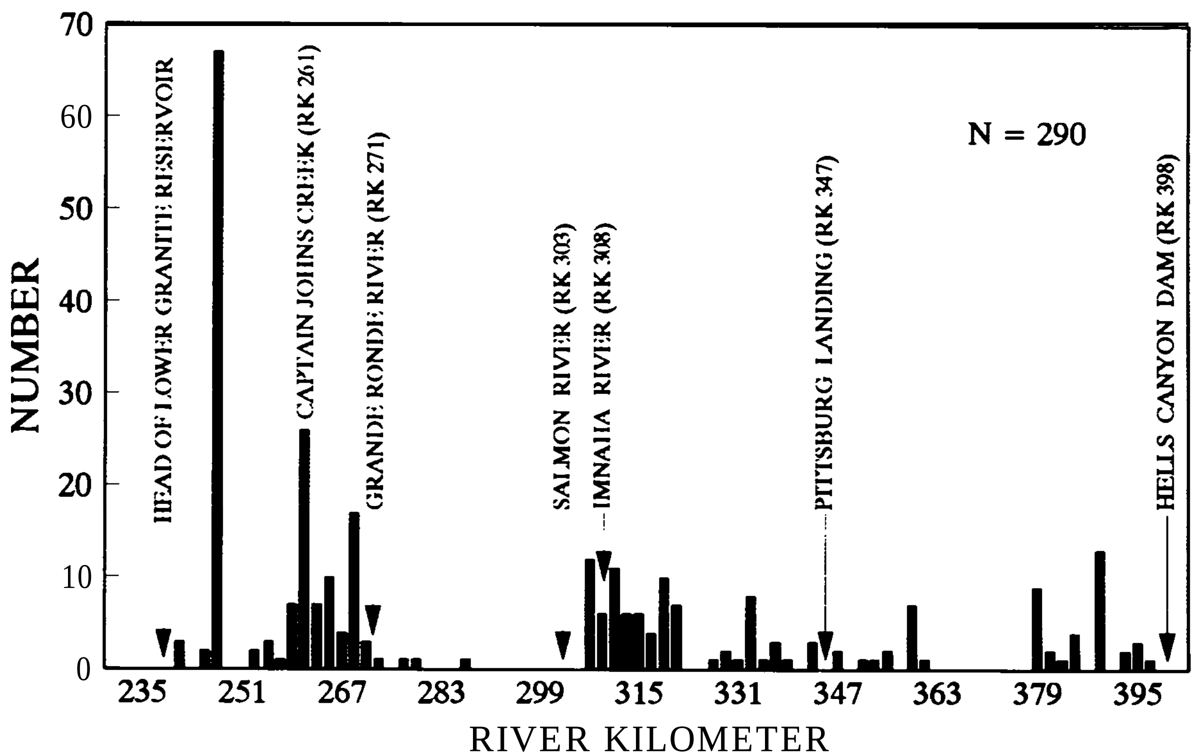

Figure 3.-Number of fall chinook salmon redds by river kilometer from index counts on the Snake River 1987-1992 (Seidel et al. 1987, Bugert et al. 1989-1991, Bugert 1991, Mended et al. 19992, and Mendel, in press).

Table 3.-River kilometer (RK), landmark, and new fall chinook salmon redds counted by date during aerial surveys of the Snake River in 1992.

RK	Landmark	New redds counted by flight date[a]								Totals
		16-Oct	23-Oct	30-Oct	OS-Nov	13-Nov	23-Nov	04-Dec	12-Dec	
245.2	Big Bench Point					1	6			7
257.1	Lower Buffalo Range	-			2		1			3
259.0	Upper Buffalo Rapids	-				6	1			7
261.3	Captain Johns Creek	-				5	4			9
266.6	Upper Billy Creek	-					1	2		3
307.3	Eureka Bar								1	1
311.7	Divide to Zig Zag	-			2	3	1			6
319.9	Above Robinson Gulch	-	-	-	-	-	3			3
332.1	Below High Range					1	1			2
344.0	Lower Pleasant Rapid	-						2		2
349.6	Coral Creek Reef							1		1
352.9	Kirby Range							1		1
	Totals:	0	0	0	4	16	18[b]	6[c]	1[d]	45

[a] The flight on 16 October covered from Pittsburg Landing (RK 347) to Asotin, Washington (RK 235), and the flight on 30 October covered from Asotin to Cochran Islands (RK 288).
[b] One potential redd was observed at RK 258.9 that was judged to be a redd from the air and therefore included in the index count for 13 November, but was not validated by ground truthing.
[c] The 6 redds counted on 4 December were observed but not considered redds during the 12 December index count, then validated by ground truthing.
[d] Two additional redds were observed by boat at RK 261.3 on 17 December, 1992.

Refinements in Redd Counts

In 1992, a total of 47 redds were counted in the Hells Canyon reach of the Snake River (Table 3). Weekly aerial redd counts totalled 45, and 2 additional redds were counted from the ground after the last aerial survey. The first redd was counted by aerial survey on 5 November, redd counts peaked on 23 November, and the last redd was counted on 12 December (Figure 4). In 1991, the first redd was counted by aerial survey on 28 October, the highest count was on 18 November, and the last new redd was counted on 9 December (Figure 5).

Six gravel disturbances observed during aerial surveys in 1992 were not judged to be redds from the air, but were subsequently determined to be fall chinook salmon redds by ground truthing. In addition, one gravel disturbance was judged to be a redd from the air on the 13 November index count, but was not verified by ground truthing. These redds account for the difference in weekly aerial counts (45) and index counts (40) in 1992.

Multiple dive passes were made on the deepwater edge of surveyed redds at RK 261 (Figure 6), RK 312, and RK 320. No redds were observed by SCUBA divers in deepwater areas at these sites in 1992.

Surveys in the Lower Monumental Dam Tailrace

We mapped roughly 4,000 m^2 of substrate, dominated by particles 2.5 cm to 15.0 cm in diameter, within the surveyed site in the tailrace of Lower Monumental Dam (Figure 7). About 7,100 m^2 of substrate dominated by 15.0 cm particles was also mapped. Areas having a dominant substrate greater than 15.0 cm contained pockets of substrate with area and particle size that appeared acceptable for spawning. Despite the presence of suitable substrate, no fall chinook salmon redds were identified during underwater surveys in the vicinity of the proposed dredge area in 1992 (Figure 8).

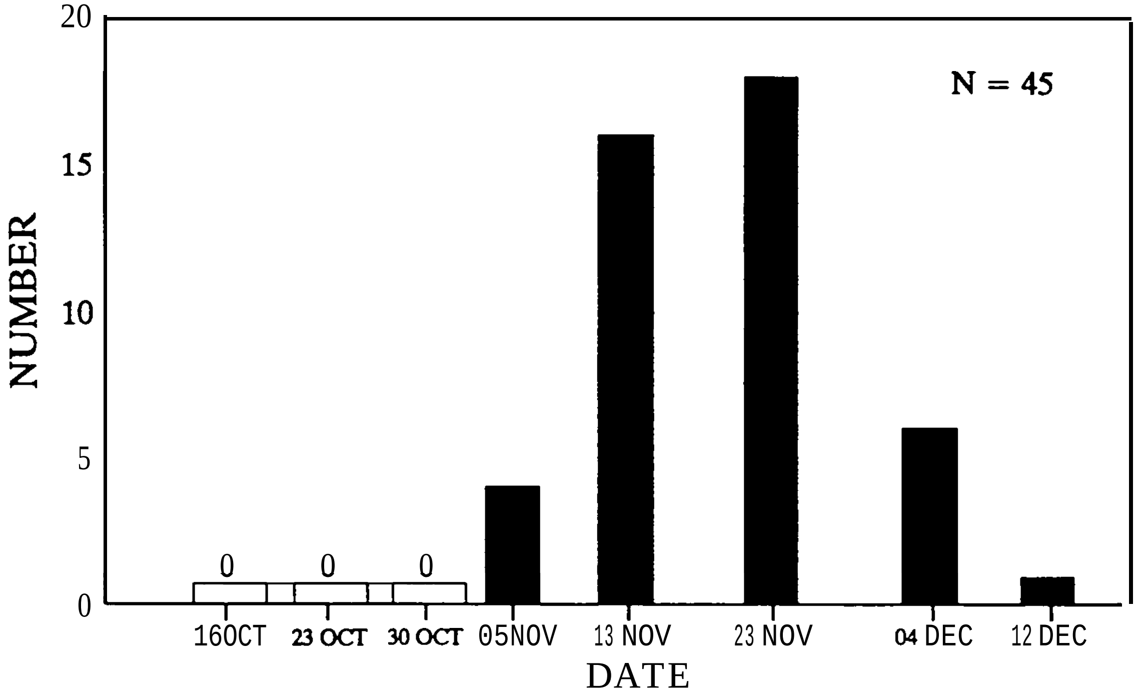

Figure 4.-Number of new fall chinook salmon redds counted on aerial surveys of the Snake River, 1992 (Data from Mendel, in press).

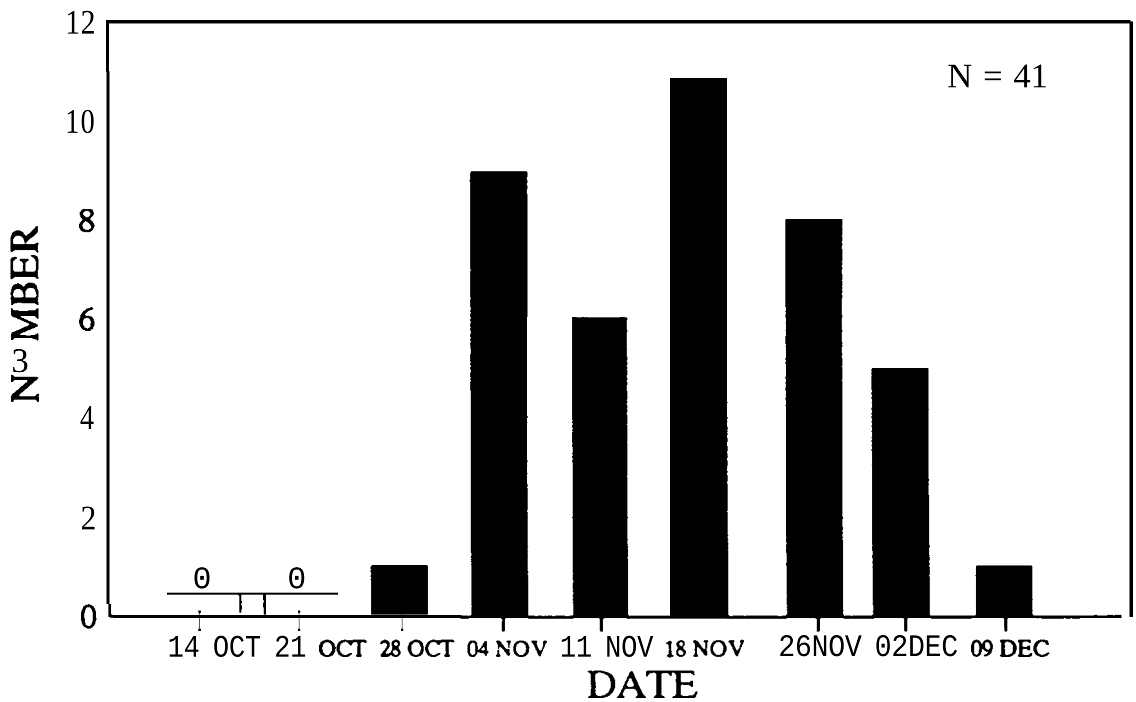

Figure 5.-Number of new fall chinook salmon redds counted on aerial surveys of the Snake River, 1991 (Data from Connor et al. 1993).

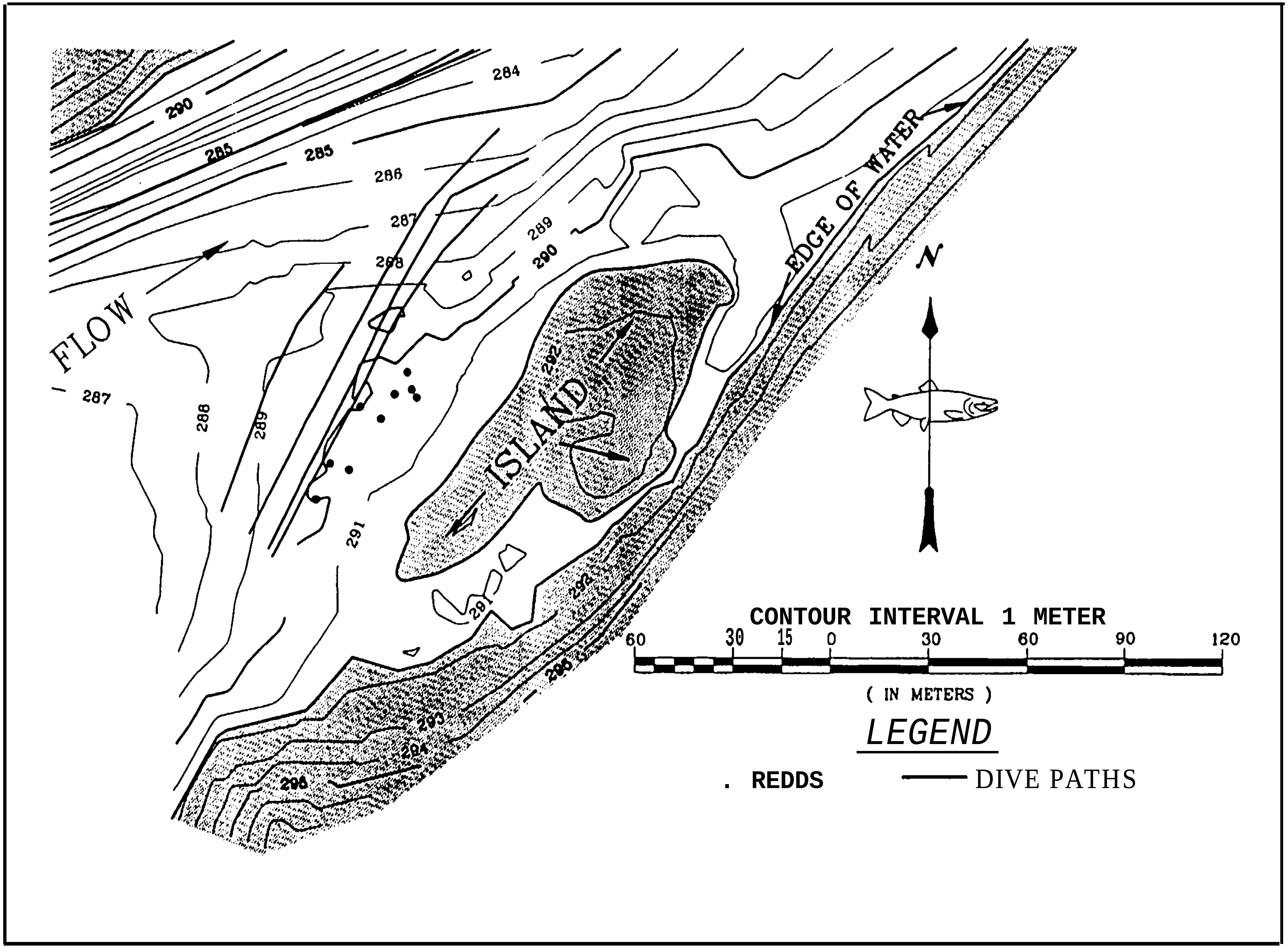

Figure 6.- Fall chinook salmon redd locations and SCUBA diver paths at RK 281 in December, 1992.

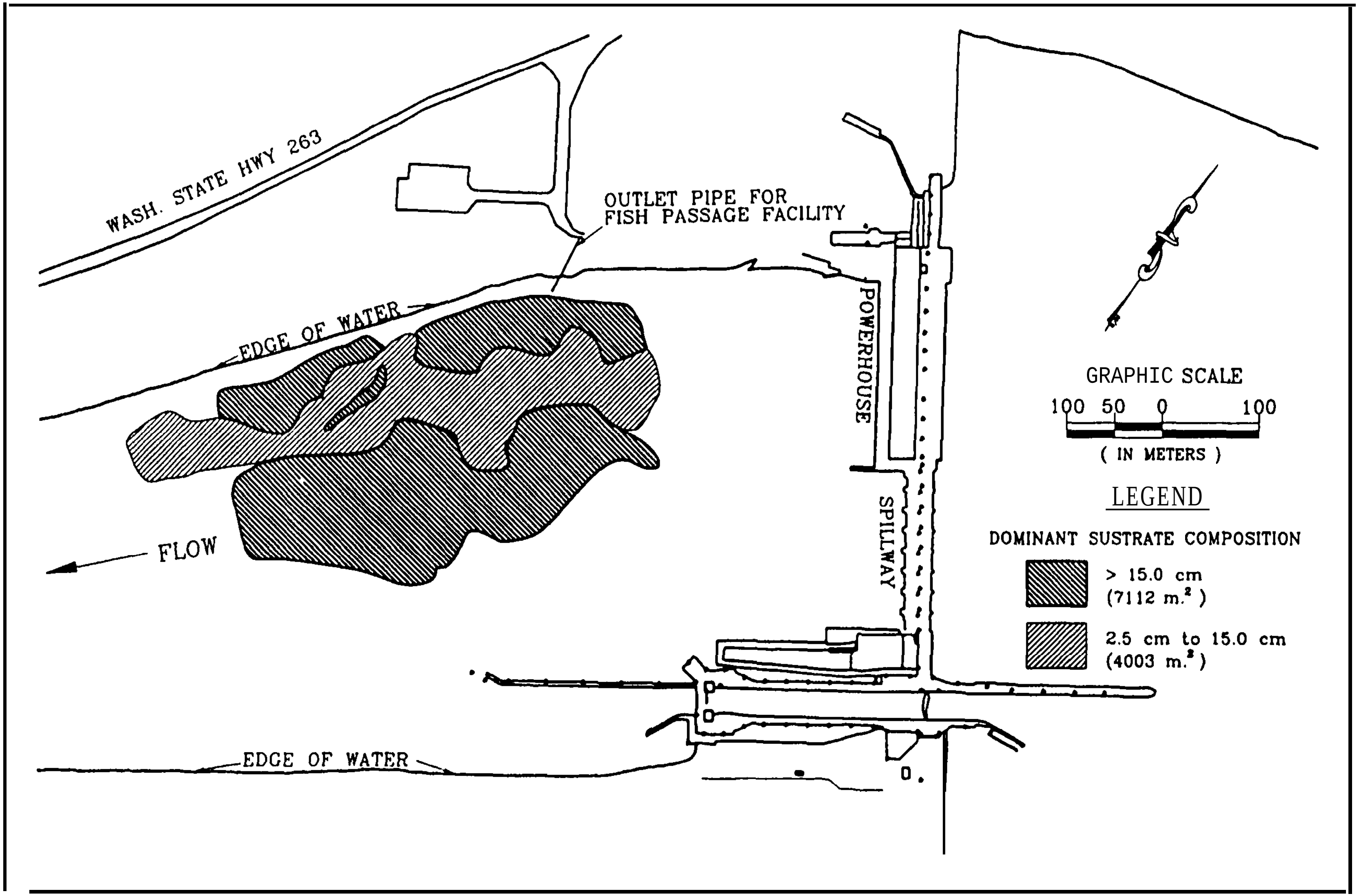

Figure '7. — Distribution of dominant substrate determined by camera then scuba divers in the tailrace of Lower Monumental Dam , October and December 1992.

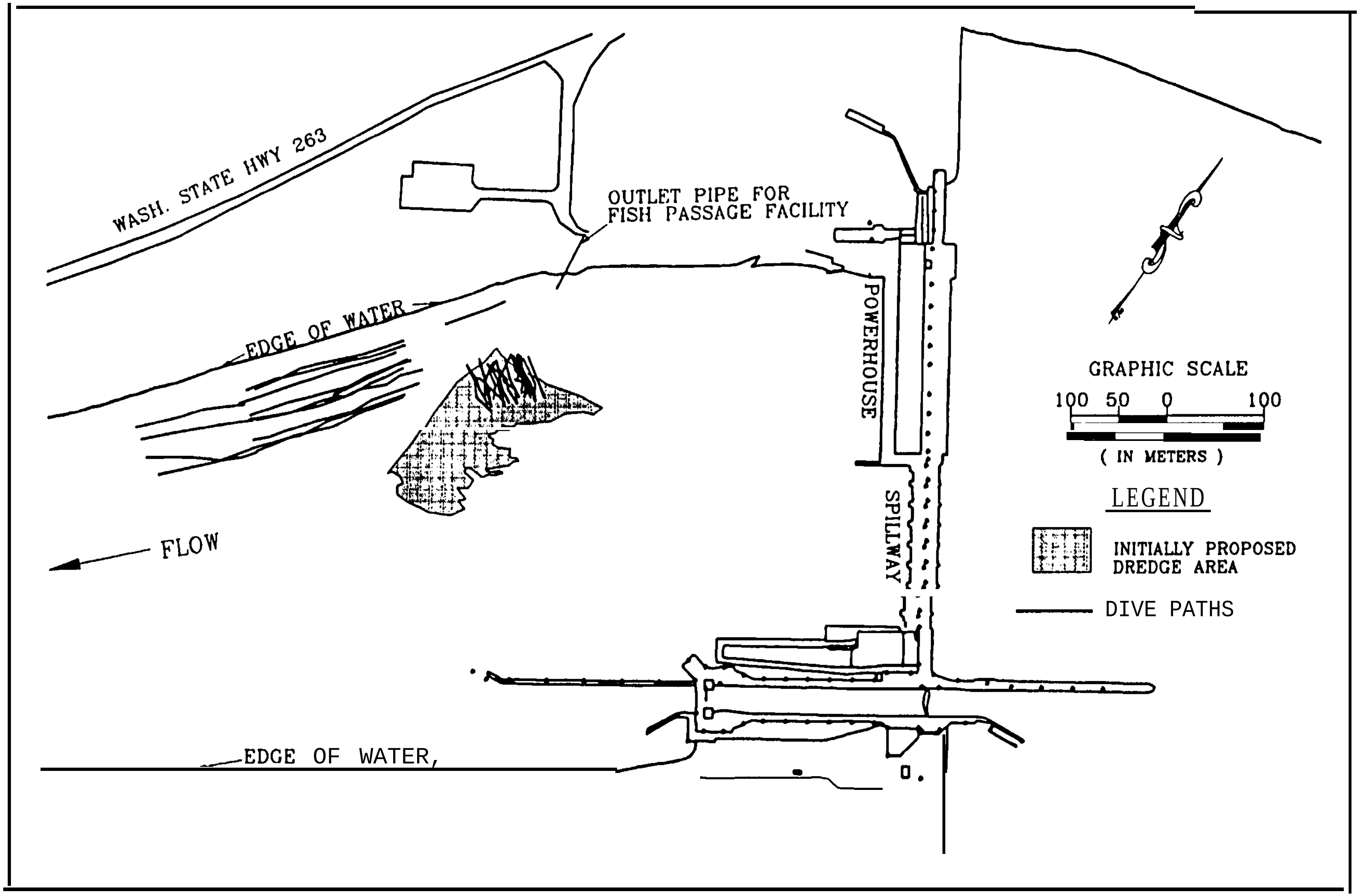

Figure 8. – Scuba diving paths through and below the proposed dredge area in Lower Monumental Dam tailrace, November and December 1992.

Discussion

Fall chinook salmon redd distribution in the Snake River shifted within the first few years after the completion of Hells Canyon Dam (Connor et al. 1993). In the early years after the completion of the dam, fall chinook spawned mostly in the upper third of the free-flowing Snake River. From 1987-1991, most spawning occurred in 31 km of free-flowing below the mouth of the Grande Ronde River (RK 271). During index counts in 1992, we observed 70% of the redds within the lower 31 km of the free-flowing Snake River. In some years, the disproportionate redd distribution in the lower river was due to concentrated spawning at a single site. This was evident in 1991 when 44% of the redds from index counts were located at RK 261. Conversely, in 1992, the majority of redds were distributed between three sites located below RK 262, and one upriver site above the mouth of the Imnaha River (RK 308) at RK 312.

Based on weekly redd count data, fall chinook salmon spawning in 1992 appears to have started later and lasted longer than in 1991. Generally, fall chinook salmon spawning in the Snake River is a November event with some spawning in late October and early December (Connor et al. 1993). In 1992, fall chinook salmon spawning in the Snake River appears to have begun in early November, peaked in the second or third week of November, and lasted well into the second, if not third, week of December.

Accuracy of fall chinook salmon redd counts by aerial survey is partially affected by observation conditions (e.g., turbidity, discharge, and cloud cover) as well as the frequency of flights; the ability to discern redds from the surrounding river bed becomes more difficult with time. In 1991, we recorded fewer redds in index counts than weekly counts primarily as a result of the longer duration between index counts. In 1992, all of the redds that were recorded in weekly counts were observed during index counts, although some were not judged to be redds from the air. The increased effectiveness of the index counts was likely due to more favorable observation conditions experienced in 1992 as compared to 1991.

The extent of deepwater spawning varied between 1991 and 1992. In 1991, we found at least five redds during underwater searches at RK 261 that had not been detected by aerial survey and ground truthing (Connor et al. 1993). In 1992, the only indication of undocumented spawning at RK 261 was found by Groves (1993). Using an underwater camera, Groves observed an area of disturbed gravel in 2 m of water that he concluded was a fall chinook salmon redd.

Deepwater spawning upstream of Lower Granite Dam (RK 173) has been identified as a source of discrepancy in the ratio of adult fall chinook salmon counts at Lower Granite Dam and the number of redds counted upstream (Connor et al. 1993) The adult-per-redd ratio has averaged 10.6/l (range, 7.4/;-15.9/l) from 1988-1992 based on index counts and redds counted in tributaries (Mendel et al. 1992, 1993). This average is reduced when deepwater redds are taken into account. To illustrate the degree in which deepwater spawning may influence adult-per-redd ratios, Connor et al. (1993) expanded index counts by 25% to reflect the number of deepwater redds at found RK 261. By doing so, the average adult-per-redd ratio (1988-1992) is reduced to 8.4/l. Although the extent of undetected deepwater spawning may be greater than was observed at RK 261 in 1991, Mendel et al (1993) reported data on radio-tagged fall chinook salmon that suggests the main source discrepancies in adult-per-redd ratios may be a result of fall chinook salmon moving back downstream after they are counted passing Lower Granite Dam.

Fall chinook spawning below Lower Monumental Dam was confirmed in February 1992 when salmon eggs and fry were found in dredged spoils in the tailrace (Kenney 1992). Surveys of substrate by underwater video camera, done prior to November 1992 in the tailrace of Lower Monumental Dam, showed suitable substrate existed for fall chinook salmon spawning. However, during fall chinook salmon redd surveys in November, underwater visibility was less than 0.5 m, limiting our ability to search for redds. Stopping water flow through the dam combined with improved underwater visibility (>2 m) allowed a more thorough redd survey in December, but new problems were encountered. Dredge disturbances on the river bed resembled fall chinook salmon redds and the repeated flushing of the dam's lock kept the dredged area free of periphyton and silt. Consequently, we did not find conclusive evidence of fall chinook salmon spawning in the tailrace of Lower Monumental Dam in 1992.

In summary, index counts of Snake River fall chinook salmon redds increased from 32 in 1991 to 40 in 1992. Weekly counts in 1992 totalled 45 compared to 41 in 1991. There was limited evidence of deepwater spawning found in the free-flowing Snake River, but no redds were found below Lower Monumental Dam. Notably, the area covered in both the free-flowing Snake River and below Lower Monumental Dam was relatively small and limited to known spawning sites.

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CHAPTER TWO

Snake River Flows and Temperature During the 1992 Snake River Fall Chinook Salmon Brood Year

by

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Introduction

Knowledge of the effects of Snake River flows and water temperatures on fall chinook salmon *Oncorhynchus tshawytscha* spawning habitat in the free-flowing Snake River is urgently needed. When the National Marine Fisheries Service was petitioned to list Snake River fall chinook salmon under the Endangered Species Act (ESA; National Marine Fisheries Service 1992), our understanding of how the operation of Brownlee, Oxbow, and Hells Canyon dams (Hells Canyon Complex) affect the spawning success of Snake River fall chinook consisted of an 18 year-old flow versus habitat study (Bayha 1974). With the ESA petition came renewed interest in obtaining information on Snake River fall chinook salmon spawning since our present understanding was not sufficient for recovery planning.

Our 1992 work was a continuation of research that began in 1991 to establish the relation between Hells Canyon Complex discharge and the availability of Snake River fall chinook salmon habitat at selected index sites (Connor et al. 1993). Study objectives for 1992 were: (1) describe Snake River discharge and water temperatures during the fall chinook salmon immigration, spawning, and egg incubation periods of the 1992 brood year and (2) model the effects of changes in river flow on fall chinook salmon spawning habitat at the RK 261 study site.

Study Area

The study area included the Snake River from Hells Canyon Dam to its mouth (Figure 1). We describe specific locations within the area in terms of river kilometers (RK) based on the navigation charts of the Snake River produced by the United States Army Corps of Engineers (COE). Our main focus in 1992 was on the free-flowing reach of the Snake River between Hells Canyon Dam (RK 398) and the head of Lower Granite Reservoir near Asotin, Washington (RK 235).

Methods

Data Collection

Discharge and water **temperature.-Snake** River provisional discharge data collected near Anatone Washington (Anatone gage; RK 270), were furnished by the United States Geological Survey (USGS) for the 1991-1993 time period (Appendix 1). The USGS also provided Snake River provisional discharge data for Hells Canyon Dam, and the Imnaha, Salmon, and Grande Ronde rivers for 1991-1993

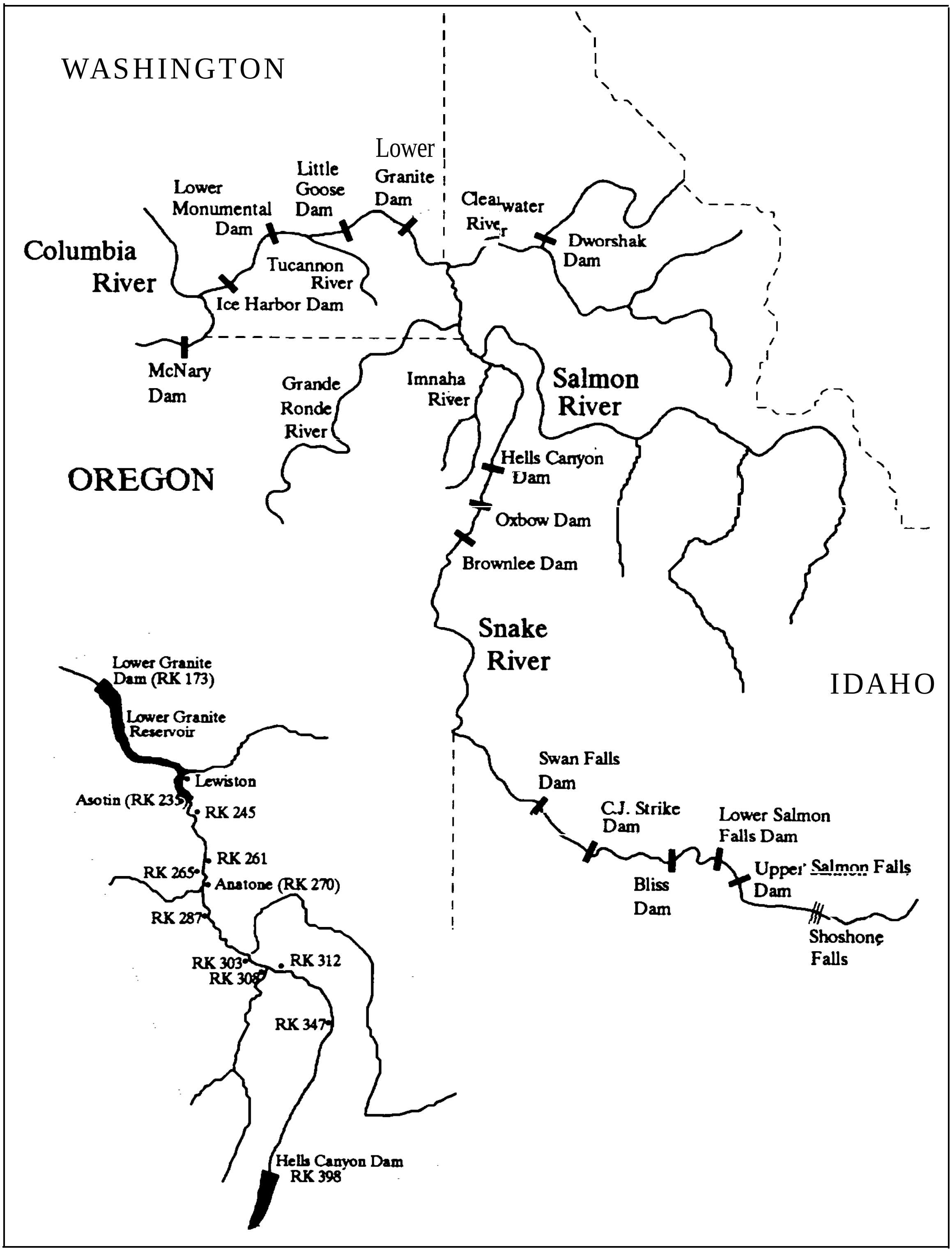

Figure l.-Map of the Snake River drainage with inset showing the 1992 fall chinook salmon spawning study site at RK 261, Anatone Gage at RK 270, Hells Canyon Dam at RK 398, and thermograph locations (refer to Table 1 for river kilometers).

(Appendix 2). Water discharge data are reported in this chapter in thousands of cubic feet per second (KCFS) based on USGS standards.

Snake River water temperature data were collected from 1991-1993 by thermograph at RK 347 and RK 265 near Pittsburg Landing and Billy Creek (Appendix 3).

Discharge and spawning habitat.-We used the Instream Flow Incremental Methodology (IFIM Bovee 1982) to collect habitat data at the fall chinook salmon spawning sites including the site located at RK 261. We collected channel elevations, water surface elevations, water velocities, and substrate codes at cross sections placed within the study site (Appendix 4). Cross sections were placed through the middle and around known spawning areas. The downstream cross section at each site was always placed at a point of hydraulic control. Because of frequent boat traffic we did not stretch a cable across the channel for positioning our gaging boat. Instead we affixed a prism to the bow of our gaging boat and surveyed the location of each flow measurement as we progressed across the channel. We also collected channel elevations and substrate codes (Brusven 1977; refer to Garcia et al. in this report for particle dimension codes) between the IFIM cross sections to allow detailed site mapping. Onshore and shallow-water channel elevations and substrate codes were measured by sighting a prism on a rod at the point of data collection. Offshore channel elevations were collected using a boat equipped with sounding gear and a prism for surveying measurement locations.

Data Analysis

Snake River discharge and water temperatures.-We used our 19 91- 1993 data (Connor et al. 1993; Connor et al. in this report; Garcia et al. in this report) to define the timing of each fall chinook salmon life stage in the 1992 and 1993 brood years (August immigration through June fry emergence) for relation to Snake River discharge. A comparison of Snake River flows was made using the 1991-1993 data.

We analyzed Hells Canyon Complex, Imnaha, Salmon, and Grande Ronde river discharge data from the 1992 fall chinook salmon brood year to demonstrate the potential effect each water source had on main stem Snake River flow volume and fluctuation at Anatone gage. Part of this analysis was based on the percentage of discharge contributed by each of the above water sources. We also examined daily changes in the discharge at the Anatone gage relative to changes in discharge of each of the above water sources.

As in our discharge analysis, we used the life stage timing of the 1991 and 1992 fall chinook salmon brood years as part of the water temperature analysis. Water temperature data from 1991-1993 collected by thermograph at RK 347 and RK 265 were compared for each fall chinook salmon life stage.

Spawning habitat modelling.-We calculated discharge, distances between cross sections, water surface elevations, site gradient, distances between vertical measurements, the mean column velocity, and the elevation of the channel bottom at each vertical. Because the measurements along a cross section were not taken from a fixed cable, there was some lateral scatter in survey points. A trigonometric conversion was used to bring the points into line and calculate a corrected location for each vertical measurement. We converted the above data into an input file for hydraulic modelling.

We selected IFG4 (Milhous et al. 1989) as our hydraulic model. The purpose of our 1992 hydraulic analysis was to simulate the depths and velocities that occurred during fall chinook spawning in 1991 and 1992 at cross section four of the RK 261 spawning study site. Cross section four was located directly through the fall chinook salmon redds surveyed in both 1991 and 1992 (Connor et al. 1993, Garcia et al. in this report). Calibration, which consists of making adjustments to the IFG4 data deck, was required prior to predicting depth and velocity.

There are two stages in the calibration of IFG4. First, a stage-discharge rating curve was fit to each cross section. IFG4 achieves this by running a log-log regression analysis on the measured stage and discharge. The resulting rating curve is in the form:

$$Q = a\,(WSE - SZF)^{b}$$

Where: Q is discharge;
a is a regression constant;
WSE is water surface elevation;
SZF is stage of zero flow; and
b is a regression constant.

The SZF is the water surface elevation at a cross-section when the flow is decreased to zero. The SZF is either the elevation of the lowest point on the cross-section or the pool water surface when a downstream hydraulic control is present. The stage of zero flow acts as a calibration variable.

Once a good fit was achieved in the stage-discharge calibration, the second step in IFG4 calibration termed "velocity calibration" was initiated. Velocity data collected during each velocity calibration flow were run through IFG4 in separate data decks. When only one velocity set is supplied in a data deck, IFG4 uses a variation of Manning's equation to calculate Manning's n for each vertical measurement. Manning's n represents channel roughness but acts as a calibration variable in IFG4. Manning's equation, when used with a single velocity data set, is written in terms of n_i at each vertical as the unknown:

$$n_i = (1.49*S_e^{1/2}*d_i^{2/3})/v_i$$

Where: n_i is the Manning's n value at vertical i
S_e is the energy slope for the cross-section;
d_i is the depth at vertical i; and
v_i is the velocity at vertical i.

The n_i values calculated at the calibration flow are then used in Manning's equation written in terms v_i of to predict the velocity at each vertical measurement at the simulated discharge. The velocity predicted at each vertical is then used to calculate the discharge in each cell across the cross section and then summed for the entire cross section, resulting in a predicted discharge.

A mass balancing procedure is used by IFG4 to ensure that the discharge predicted by a velocity set is equal to the simulated discharge. The simulated discharge is divided by the discharge predicted by the velocity set to yield a velocity adjustment factor (VAF). The velocity at each vertical is then multiplied by the VAF to yield a final velocity profile for the simulated discharge.

Gaged flows that were not used as the calibration flow were then simulated and the resulting predicted velocity profiles were compared to the gaged velocity profiles. Velocity calibration consists of modifying the n values, when there is a physical reason to do so, to achieve a reasonable velocity profile. Extreme flows (minimum of **5.0** KCFS and maximum of 99.0 KCFS) were also simulated in order to find any inappropriate velocities and n values.

After we completed the above two steps of data deck calibration, we proceeded with simulation of the water depths and velocities of the fall chinook salmon spawning area at RK 261 using the hydrograph of the 1992 fall chinook salmon brood year. Three distinct points along cross-section four were chosen to represent the center of the spawning site, the shallow edge of the spawning site and the deep edge of the spawning site. These points coincide closely with the actual **locations and elevations** of redds observed during the 1992 spawning season. Depth and velocity over each of these points was extracted from the model output for the range of simulated flows.

Results

Discharge

Snake River average daily discharge differed substantially between the 1991 and 1992 brood years (Figure 2). During the 1992 brood year immigration, adult fall chinook salmon experienced discharges (mean 12.2 KCFS; range 9.2-15.1 KCFS) that were 77% of immigration flows in 1991 (15.8 KCFS; range 11.0-23.3 KCFS). During fall chinook salmon spawning in the 1992 brood year, discharge (mean 13.4 KCFS; range 11.8-14.3 KCFS) was about 85% of the 1991 mean (15.7 KCFS; range 13.9-19.5 KCFS). During fall chinook salmon egg incubation of the 1992 brood year, discharge (mean 35.5 KCFS; range 11.8-118.0 KCFS) was about 171% of the 1991 mean (20.7 KCFS; range 13.9-47.2 KCFS). During fall chinook salmon fry emergence of the 1992 brood year, discharge (mean 68.1 KCFS; range 25.9-118.0 KCFS) was about 252% of the 1991 mean (27.0 KCFS; range 18.4-47.2 KCFS).

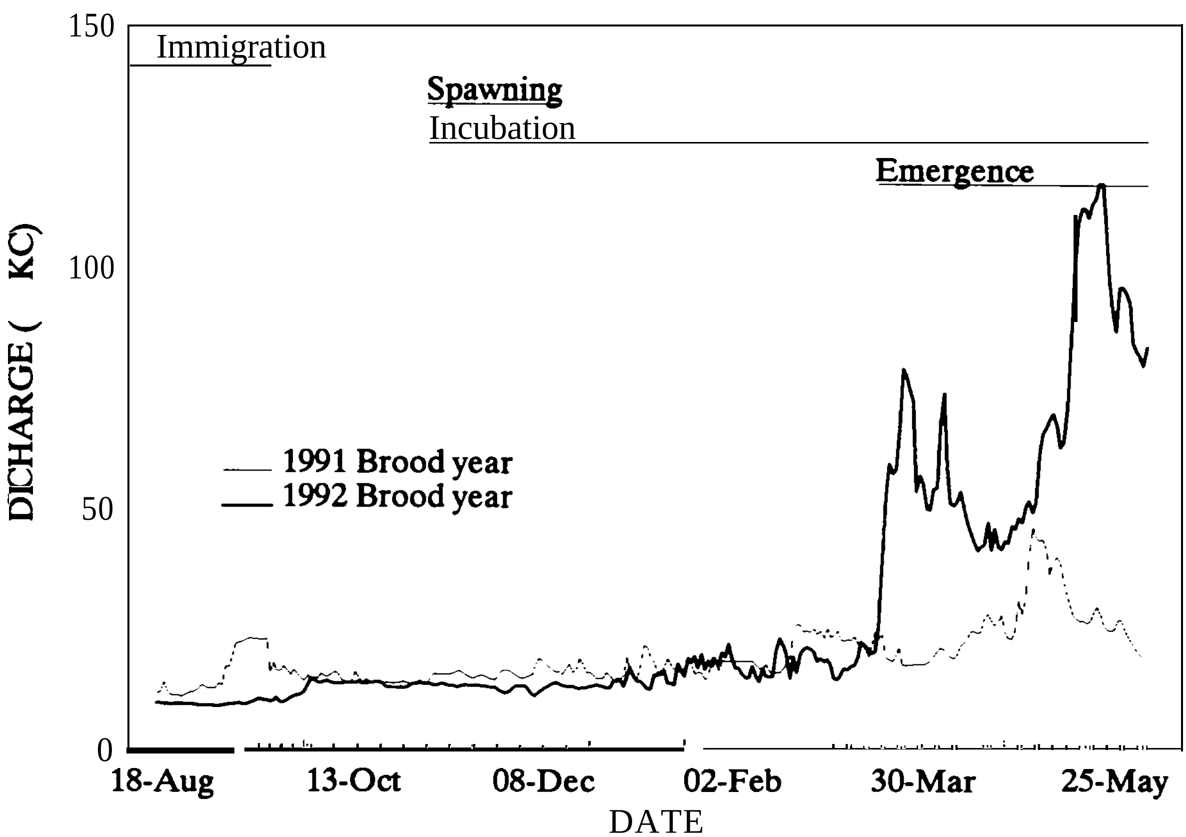

Figure 2.-Snake River average daily discharge for the 1991 and 1992 fall chiook salmon brood years. Provisional discharge data were provided by the Umted States Geological Survey for Anatone gage, Washington.

Hells Canyon Complex water releases made up most of the Snake River's discharge measured at Anatone gage during adult fall chinook salmon immigration (69%), spawning (68%), early egg incubation (71%) and late egg incubation (50%) for the 1992 brood year (Table 1). The Salmon River contributed from 21-31% of the discharge gaged at Anatone over the 1992 fall chinook salmon brood year. The Grande Ronde's contribution of flow for the 1992 fall chinook salmon brood year ranged from S-12%. Imnaha River contributed comparatively little discharge (range l-2%) to the main stem Snake River at the Anatone gage for the periods described above.

Table l--Discharge contribution by Hells Canyon Dam, Imnaha River, Salmon River, and the Grande Ronde River to the main stem Snake River at the Anatone gage of Washington during the 1992 fall chinook salmon brood year. Total flow does not always sum to 100 percent because the gage stations are not synchronized and the data were provisional.

Life stage	Date	Percent of Snake River discharge contributed by source			
		Hells Canyon Dam	Imnaha River	Salmon River	Grande Ronde River
Immigration	18 Aug - 23 Nov 92	69	1	26	5
Spawning	5 Nov - 12 Dec 92	68	1	25	6
Early incubation	5 Nov-92 - Feb 17 93	71	1	21	6
Late incubation	18 Feb - 4 Jun 93	50	2	31	12

Since Hells Canyon Complex discharge dominated the Snake River's flow volume at Anatone gage, it also influenced the pattern of daily flow fluctuation throughout the 1992 fall chinook salmon brood year (Figure 3). The largest fluctuation at Anatone gage during 1992 immigration was a 3.3 KCFS increase over the period of 29 September (11.8 KCFS) to 2 October (15.1 KCFS). This 3.3 KCFS increase was attributable to a 3.8 KCFS rise in Hells Canyon Complex flows during the same period of time. Subsequently, there was little flow fluctuation during immigration until 24 October when Hells Canyon Complex flows were dropped by 1.2 KCFS (10.3 to 9.1 KCFS). This reduction in Hells Canyon Complex flows on 24 October was followed by a 1.2 KCFS drop in Snake River flow at Anatone gage by 25 October.

Snake River discharge measured at Anatone gage during 1992 fall chinook salmon spawning averaged 13.4 ± 0.6 KCFS (range 11.8-14.3 KCFS; Figure 3). The largest discharge fluctuation for a 24-h period of spawning was a 1.0 KCFS drop measured at Anatone on 5 December. This 1.0 KCFS decrease at Anatone gage was

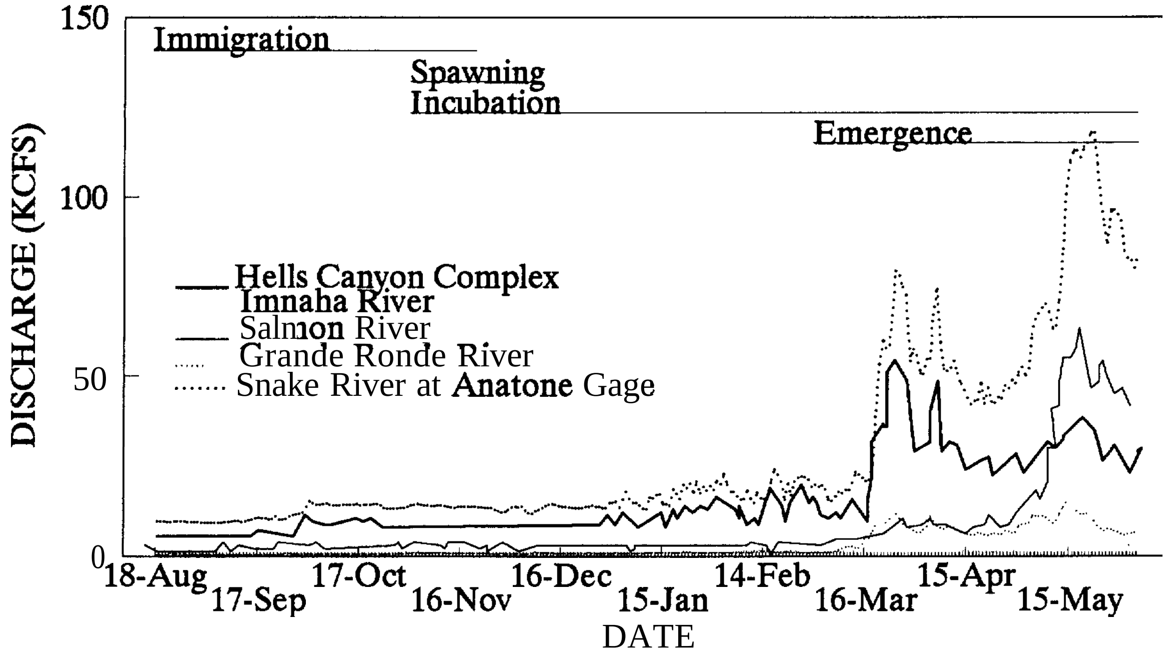

Figure 3.-Average daily discharge at Hells Canyon Dam, Imnaha River, Salmon River, Grande Ronde River, and the main stem Snake River at Anatone Gage, Washington during the 1992 fall chinook salmon brood year. Provisional data were provided by the United States Geological Survey.

attributed to decreases in Salmon River flows of 1.5 KCFS and 0.8 KCFS on 27 November and 5 December, respectively. The highest flow (14.3 KCFS) during fall chinook salmon spawning occurred on 12 December, 1992. The last date new fall chinook salmon redds were counted in 1992 was also on 12 December (Garcia et al. in this report). Snake River discharge at Anatone gage was below 14.3 KCFS 37% (21 d) of the time during early fall chinook salmon egg incubation (decrease ranged from 0.1-1.2 KCFS). Most of the flows which were below 14.3 KCFS were caused by the low flows in the Salmon River. On 10 January, 1993 the Salmon River dropped 1.19 KCFS which accounts for all but .01 KCFS of the maximum 24-h decrease of 1.2 KCFS during the early part of fall chinook salmon egg incubation.

The erratic hydrograph that began about 3 January was indicative of hydroelectric generation by Hells Canyon Complex, often termed power peaking (Figure 3). Hells Canyon Complex discharge fell below its highest flow release (9.4 KCFS) that occurred during fall chinook salmon spawning for 2 d during the egg incubation period. The maximum difference between the high spawning flow of and the low flow during incubation was 0.6 KCFS.

A marked increase in Snake River discharge at Anatone gage began on 19 March, 1993 with the start of spring runoff (Figure 3). The spring runoff pattern through fall chinook salmon fry emergence was bimodal. The early peak occurred on 25 March (79.7 KCFS) and was dominated by Hells Canyon Complex flows of 48.6-54.8 KCFS. The late peak occurred on 21 May and was comprised of **mostly** Salmon River water (60.2-64.2 KCFS).

Water Temperature

Snake River average daily water temperatures at RK 347 were similar between the 1991 and 1992 brood years until early into the fall chinook egg incubation period (Figure 4). During the 1992 brood year immigration, adult fall chinook salmon experienced water temperatures (mean 17.1°C; range 10.9-21.1°C) that were comparable to water temperatures in 1991 (mean 17.6°C; range 11.1-21.3°C). During fall chinook salmon spawning in the 1992 brood year, water temperature (mean 10.3°C; range 6.8-13.9°C) was within 1.0°C of the 1991 mean (10.9°C; range 7.5-14.9°C). During the early part of fall chinook salmon egg incubation of the 1992 brood year, **water** temperature (mean 6.1°C; range 1.5-13.9°C) was cooler than the 1991 mean (7.7°C; range 3.9-14.9°C). The cooler pattern in water temperatures between 1992 and 1991 brood years continued through the later part of egg incubation (1992 mean 7.2°C; range 1.5-16.6°C and 1991 mean 8.1°C; range 3.6-13.5°C). During fall chinook salmon fry emergence of the 1992 brood year, water temperature (mean 10.8°C; range 4.1-16.6°C) was cooler than the 1991 mean (12.5°C; range 9.5-15.4°C).

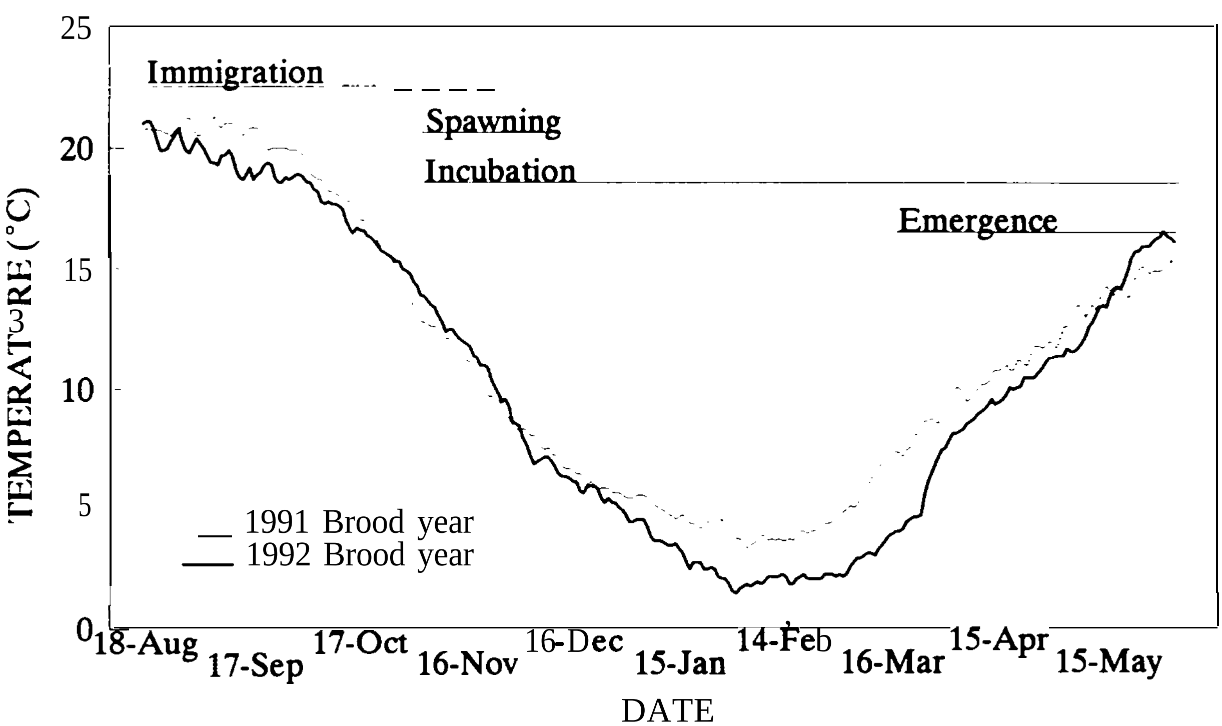

Figure 4.-Average daily Snake River water temperatures at RK 347 for the 1991 and 1992 fall chinook salmon brood years.

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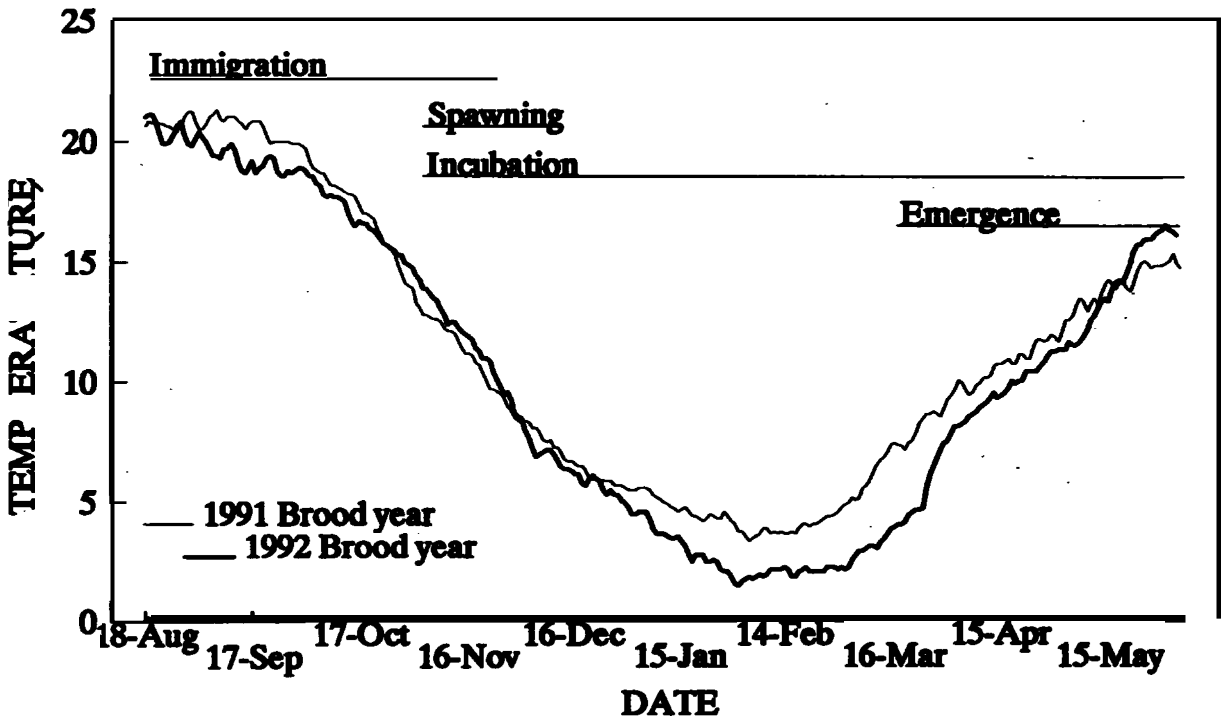


Figure 4.-Average daily Snake River water temperatures at RK 347 for the 1991 and 1992 fall chinook salmon brood years.

The comparison of Snake River mean daily water temperature at RK 265 between the 1991 and 1992 fall chinook salmon brood years (Figure 5) is quite similar to that described above at RR 347. During the 1992 brood year immigration, fall chinook salmon were subjected to temperatures (mean 15.9°C; range 8.5-22.5°C) that were'cooler than in.1991 (mean 16.4°C; range 8.9-21.8°C). During fall chinook salmon spawning in the 1992 brood year, water temperature (mean 8.1°C; range 4.9-11.7°C) was cooler than the 1991 mean (8.7°C; range 6.0-12.4°C). During the early part of fall chinook salmon egg incubation of the 1992 broodyear, water temperature (mean 4.9°C; range 1.6-11.7°C) was cooler than the 1991 mean (6.3°C; range 3.3-12.4°C). During the later part of fall chinook salmon egg incubation of the 1992 brood year, water temperature (mean 7.2°C; range 1.6-14.0°C) averaged 1.6°C cooler than water temperature of 1991 (8.8°C; range 3.1-14.0°C). During fall chinook salmon fry emergence of the 1992 brood year, water temperature (mean 10.4°C; range 5.6-14.0°C) was cooler than the 1991 brood year mean (13.0°C; range 9.5-17.5°C).

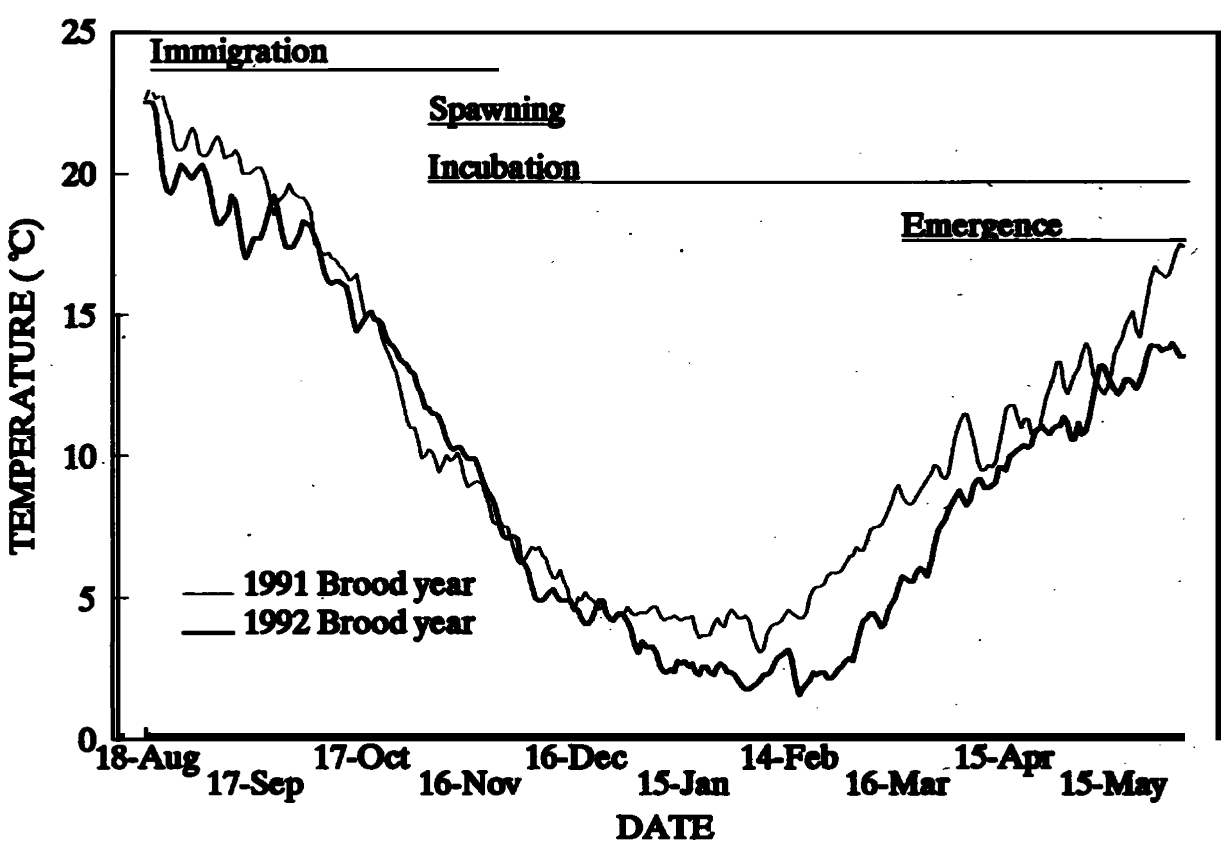


Figure 5.-Average daily Snake River water temperatures at RK 265 for the 1991 and 1992 fall chinook salmon brood years.

The Snake River was generally warmer upriver (RK 347) 'than downriver (RR 265) through fall chinook salmon spawning and early egg incubation of the 1992 brood year, until 18 January when the temperatures became similar (Figure 6). During fall chinook salmon immigration of the 1992 brood year, mean daily water temperature varied by river kilometer and was warmer upriver (RK 347 mean 17.1°C; RR 265 mean 15.9°C). The Snake River remained warmer at RR 347 than at RR 265 through fall chinook salmon spawning (means 10.3°C and 8.1°C). Upriver water temperature continued to be warmer than downriver water temperature through early incubation (RR 398 mean 6.1°C; RR 265 mean 4.9°C) until 18 January, 1993 when up and downstream Snake River water temperatures became similar (RR 398 mean 7.2°C; RR 265 mean 7.2°C). The Snake River did not go below freezing at either RR 347 or RR 265 during the 19-92 fall chinook salmon brood year (minimums 1.5°C and 1.6°C, respectively). Snake River water temperatures were comparable up and downstream for the first 52 d of fall chinook salmon fry emergence (means RR 347 9.1°C and RR 265 9.3°C). The upper river became warmer (RR 398 mean 15.3°C; RK 265 mean 9.3°C) over the last 21 d of emergence starting on 14 May.

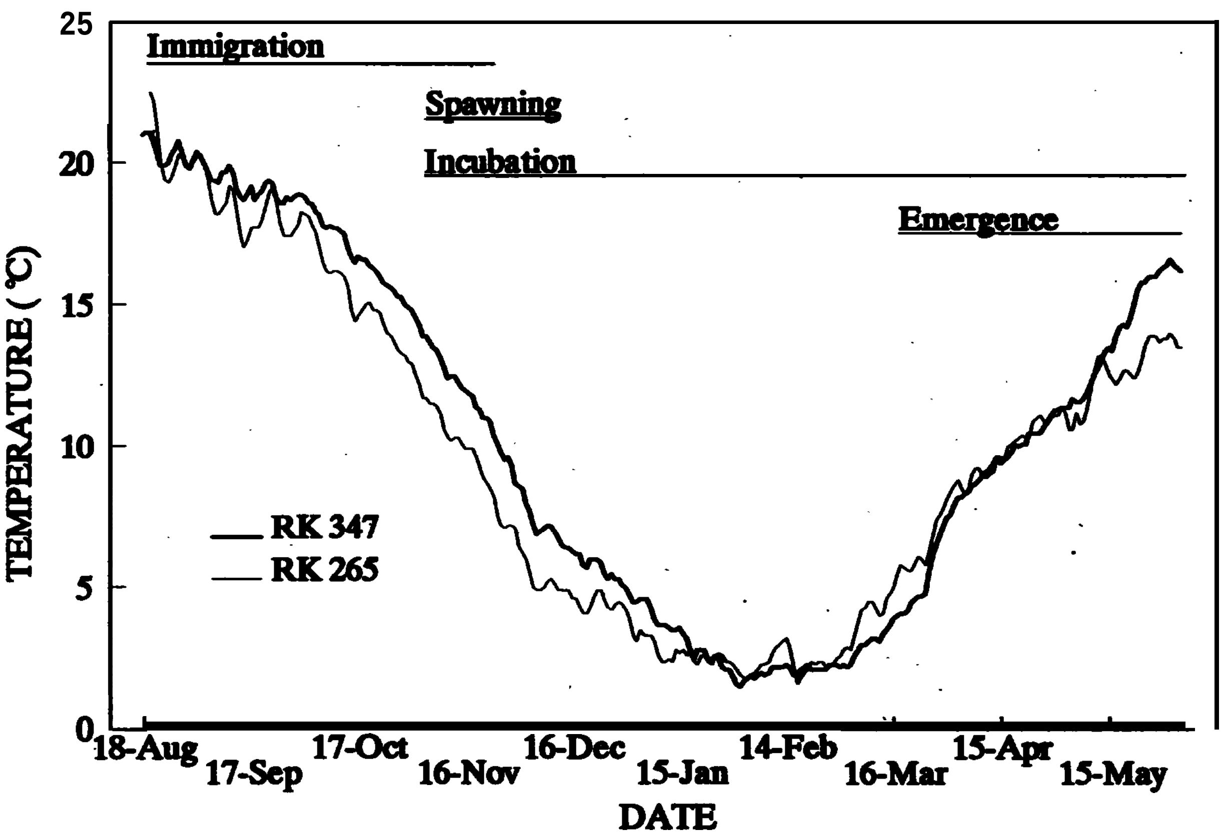


Figure 6.-Average daily Snake River water temperatures at RK 347 and RK 265 for the 1992 fall chinook salmon brood years.

Spawning Habitat Modelling

Water depths simulated using IFG4 at cross section four of the RK 261 spawning study site (Figure 7) varied considerably over the range of discharges during the 1992 fall chinook salmon brood year (Figure 8). Simulated water depth at the point representing the center of the spawning site ranged from 0.7-0.9 m over the range of discharges occurring during spawning in 1992. Simulated water depth at the point representing shallow redds ranged from 0.3-0.5 m during the same time period, while simulated water depth at the point representing deep redds ranged from 1.0-1.2 m.

The model predicted that the point representing the shallow redds would be dewatered at discharges of 7.4 KCFS and less. The center redds would be dewatered at discharges of 5.4 KCFS and less. Deep water redds would remain submerged at 5.0 KCFS, the lowest discharge modelled. No redds would be dewatered over the range of flows recorded during the 1992 fall chinook salmon brood year.

Mean water column velocities simulated using IFG4 at the spawning site at RK 26i also varied considerably from the shallow redds to the deep redds (Figure 9). Simulated mean column velocity at the point representing the center of the spawning site ranged from 0.8-1.0 m/s over the range of discharges occurring during spawning in 1992. Simulated mean column velocity at the shallow redds ranged from 0.3-0.5 m/s during the same time period while mean column velocity at the deeper redds ranged from 0.9-1.1 m/s.

The mean discharge during the fall chinook salmon spawning period was 2.3 KCFS less in 1992 than in 1991. Thus, the water surface elevation and velocities across the cross section were less in 1992 than in 1991 (Figure 10). The simulated water surface elevation at the mean spawning discharge was 0.2 m less in 1992 (291.2 m) than in 1991 (291.4 m). The simulated mean channel velocity at the mean spawning discharge was 0.1 m/s less in 1992 (1.1 m/s) than in 1991 (1.2 m/s). The mean column velocity over the center of the redds at the mean spawning discharge was 0.2 m/s less in 1992 (0.9 m/s) than in 1991 (1.1 m/s).

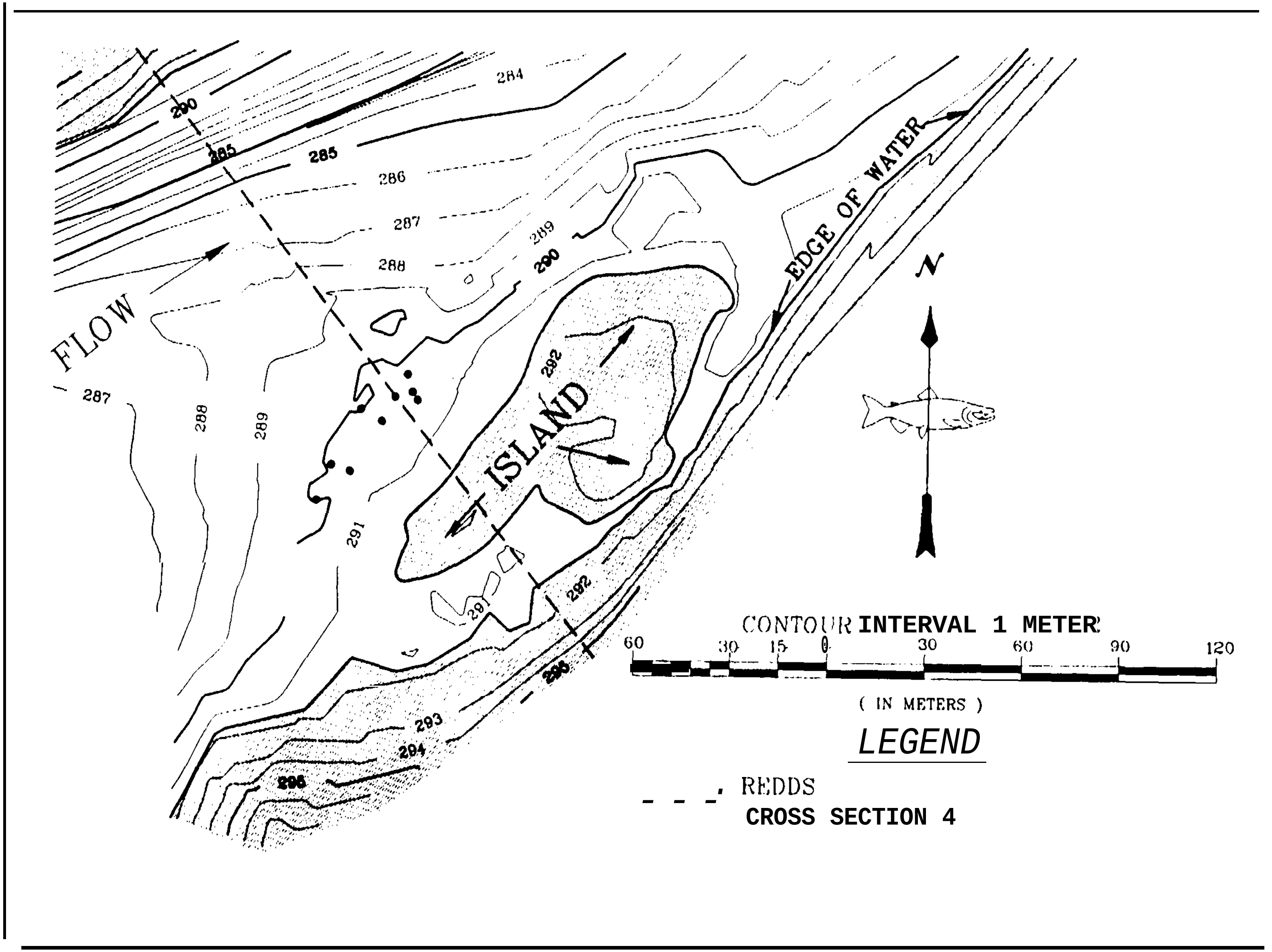


Figure 7.– Location of cross section four across fall chinook salmon spawning habitat at RK 261.

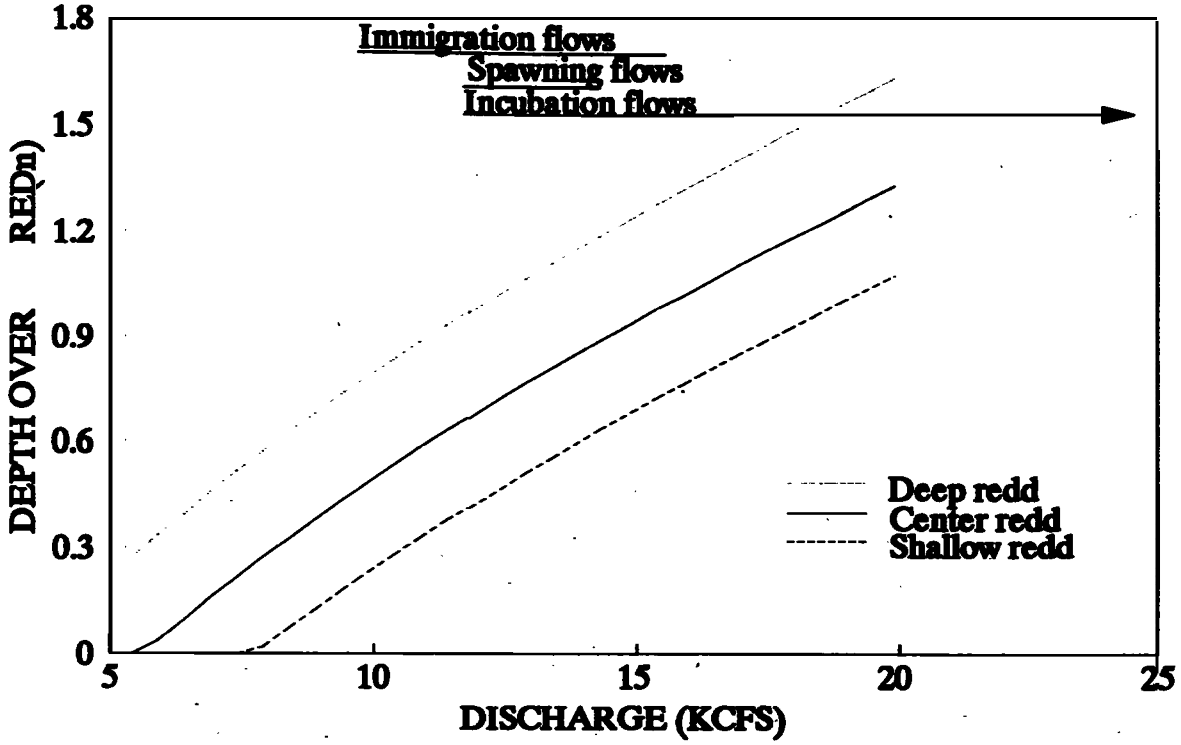


Figure 8.-Water depths at points representing the center of the spawning site at RK 261, the shallow edge of the spawning site and the deep edge of the spawning site, as modeled using IFG4.

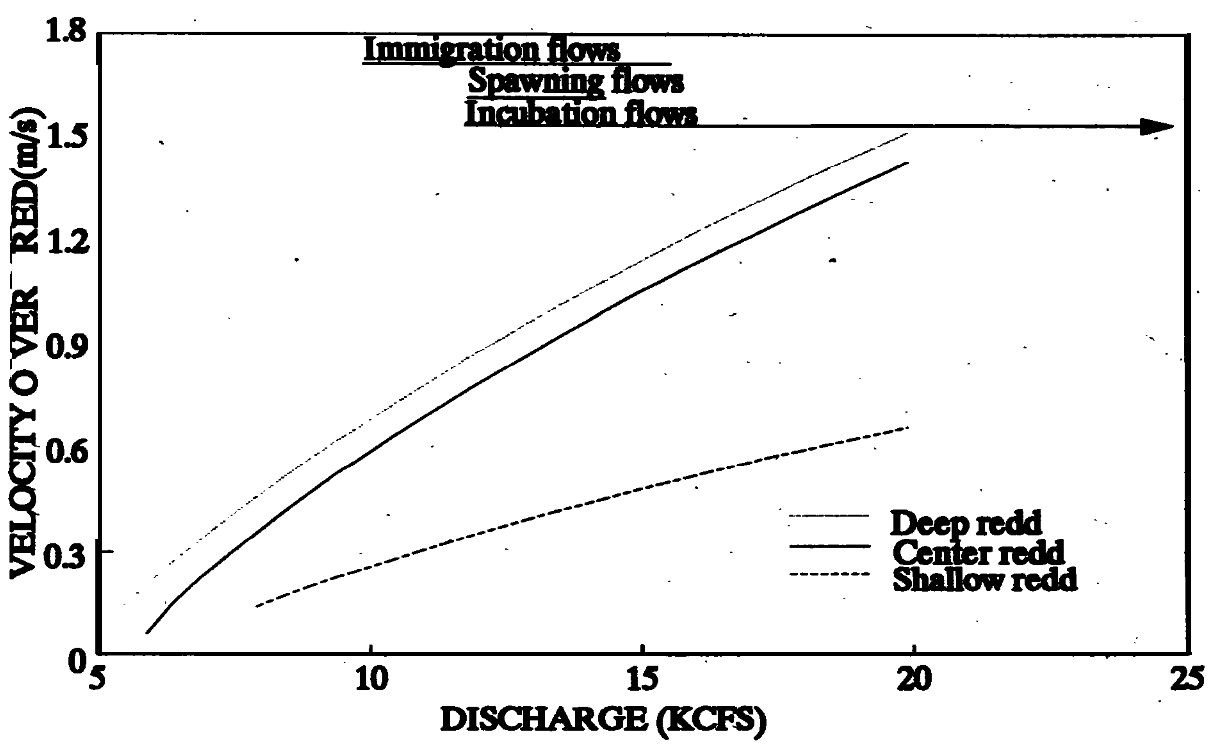
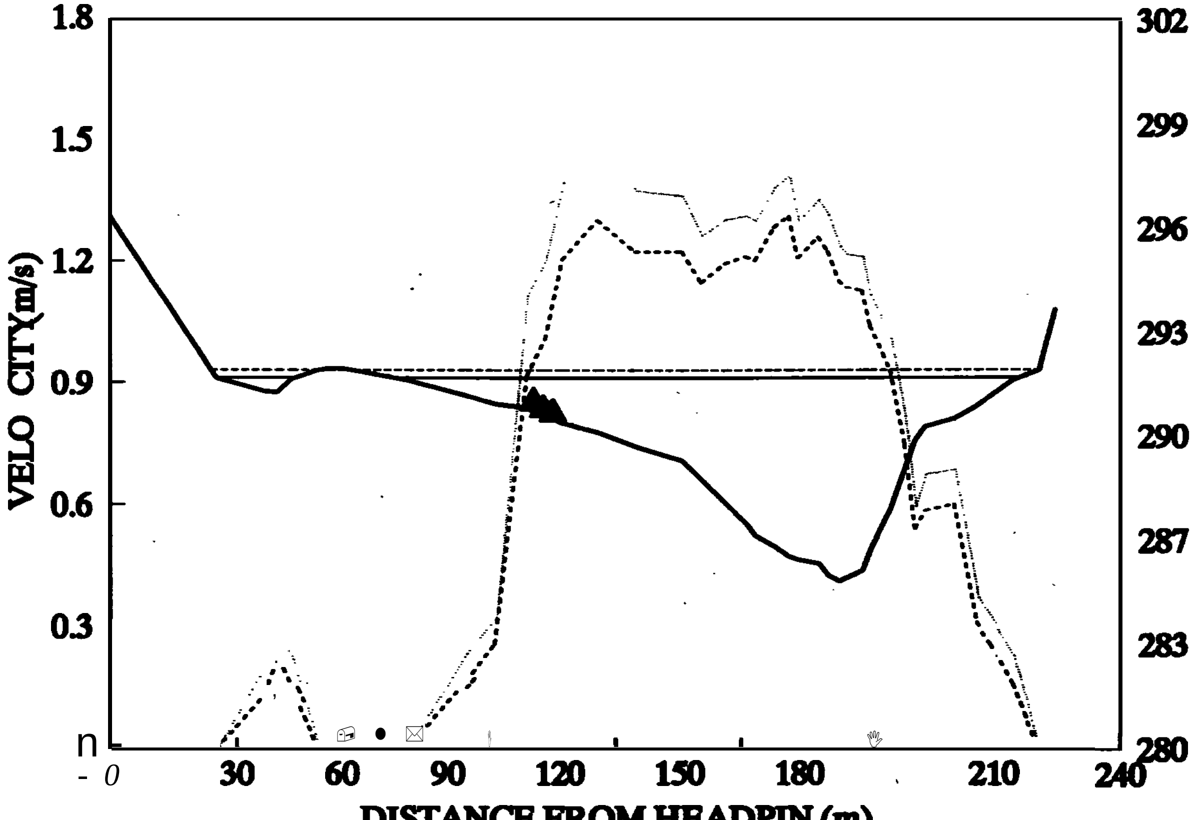


Figure 9.-Water velocities at points representing the center of the spawning site at RK 261, the shallow edge of the spawning site and the deep edge of the spawning site, as modeled using IFG4.



————	Water surface elevation at average discharge during spawning 1991.
....	Velocity profile at average discharge during spawning 1991.
————	Water surface elevation at average discharge during spawning 1992.
- - - - -	Velocity profile at average discharge during spawning 1992.
————	Channel bottom elevation
▲▲	Redd locations, 1991 and 1992.

Figure 10.-Velocity profiles and water surface elevations at cross section four at RK 261, as modeled using IFG4.

Discussion

Snake River discharge during the 1992 fall chinook salmon brood year varied by life stage and differed from 1991 brood year flows. Flows in the 1992 brood year were generally lower than 1991 brood year during immigration, spawning, and early egg incubation. As fall chinook salmon fry of the 1992 brood year began to emerge flows increased dramatically and exceeded 1991 brood year flows by an average of 40 KCFS. As in the 1991 brood year (Connor et al. 1993), the operation of Hells Canyon Complex dominated the shape of the Snake River's flow regime at Anatone gage (RK 270). Consequently, the ongoing effort of the Idaho Power Company (IPCo) to prevent fall chinook salmon redd dewatering between Hells Canyon Dam and the mouth of the Salmon River (RK 302) appears to have had positive effects as far downriver as Anatone gage (RK 270). As in the 1991 brood year (Connor et al. 1993), flows increased to their highest level during the spawning period on the last day of fall chinook salmon redd counts (12 December). The 12 December increase in 1992 appears to have been related to Salmon River flows and resulted in a discharge at Anatone gage of 14.3 KCFS. Discharge at Anatone gage fell below 14.3 KCFS often during fall chinook egg incubation prior to 17 March, but the greatest difference was only 1.2 KCFS. After 17 March, high spring flows commenced and there was no danger of redd dewatering through the end of fall chinook salmon fry emergence in June.

We found that Snake River water temperatures during the 1992 fall chinook salmon brood year were similar to those of the 1991 brood year until the snow melt and rainfall of early spring began about 17 March. After 17 March, the cooler egg incubation conditions of brood year 1992 had major effects on the timing of fall chinook salmon fry emergence in the spring of 1993. To date, we know of no calibrated temperature model capable of showing the effects of Hells Canyon Complex on fall chinook salmon egg incubation rate in the the Snake River.

We developed models to predict the effects of flow on fall chinook salmon spawning habitat in 1992-1993. To demonstrate our progress with the models we presented results from a complicated fall chinook salmon spawning study site at RK 261. These results illustrate a number of important points. We determined that the errors associated with flow gaging done without being attached to a fixed cable were mathematically correctable. Furthermore, the model we calibrated with the above data simulated depths and velocities accurately when compared to measured data. Our confidence in the modelling results is furthered by a comparison to the data of Groves (1993). Groves measured depth and mean column velocity directly over 10 of the fall chinook salmon redds at RK 261 in 1992. The range of depths (0.7-1.4 m) measured by Groves corresponded closely to the range of depths predicted for representative points within the spawning area by our model (0.5-1.2 m). Likewise, the mean column velocities (0.7-1.2 m/s) measured by Groves over fall chinook redds were similar to those representative points we modelled (0.4-1.1 m/s). Accurate hydraulic models of fall chinook spawning sites will help isolate the physical features of areas that attract spawners on a consistent basis. In our reports (Connor et al. 1993, and Garcia et al. in this report), we discuss the occurrence of concentrated spawning at a few sites since 1987. To date there is no explanation for this phenomenon. An explanation of concentrated spawning will be necessary to estimate the production potential of the spawning sites in future reports. For the present, our calibrated model could be useful for describing the effects of flow alternatives on select fall chinook salmon spawning sites.

In conclusion, our findings during 1992 indicate: (1) Hells Canyon Complex dominated the flow pattern of the Snake River downstream to RK 270; (2) the thermal regime of the Snake River was colder during egg incubation and fry emergence during 1992 than during 1991; (3) our calibrated hydraulic model of RK 261 indicated that depths and velocities at RK 261 were different in 1991 and 1992 during spawning; and (4) our model predicted that the flow required to dewater the shallowest fall chinook redds at RK 261 would be 7.4 KCFS (gaged at RK 270), which is well below any actual flow event which occurred during fall chinook salmon spawning or egg incubation of 1991 or 1992. Finally, the information we have presented in this chapter will be modified upon the analysis of additional data.

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CHAPTER THREE

Swimming performance of subyearling chinook salmon

by

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Introduction

Seasonal reductions in the swimming performance of juvenile salmon have been proposed as a behavioral mechanism that enables juvenile salmon to emigrate. The observed decrease in swimming performance and an analysis of migration rates led Smith (1982) to develop the paradigm that in the Columbia River, yearling salmonids migrate during part of a day by swimming upstream with the reduced performance. This paradigm may be applicable to the migratory behavior of juvenile fall chinook salmon *Oncorhynchus tshawytscha*. Relatively little is known about what factors might prompt the changes in swimming performance in preparation for seaward migration, but physiological readiness and environmental stimuli are possible factors. One factor in particular, the influence of flow on the timing and rate of emigration of fall chinook salmon in the Columbia River Basin has been controversial.

This laboratory study was initiated in 1991 to describe the swimming performance of juvenile fall chinook salmon and to estimate the influence of environmental and biological factors or directing and regulating their performance (Nelson et al. 1993). The objectives in 1992 were to provide additional information on whether juvenile fall chinook salmon emigrate actively or passively and the influence of flow, temperature, fish size, and smoltification level on their rate of emigration.

Methods

The basic study design and equipment remained the same **as** in 1991 (Nelson et al. 1993). Fish were subjected to increasing water velocities during the day and night and their swimming performance quantified. However, the source of fish used in the 1992 experiments was different from 1991.

Fish Collection

Subyearling chinook salmon were collected from McNary Pool and McNary and John Day dams. Twenty fish, assumed to be rearing in McNary Pool, were randomly selected from beach seine catches made every other week from 6 May to 30 June. The fish were transported about 300 km to the laboratory and transferred to the test flume. During transport, the fish were supplied with oxygen, and the water temperature at the time of collection was maintained to ±2°C. The fish were allowed to acclimate to the test flume at least 24 h before testing. Water velocity in the test flume during acclimation **was** 0-l cm/s. Fish were not fed during this time.

Twenty fish from McNary Dam were collected every other week from 10 June to 19 August, and 20 fish from John Day Dam were collected every other week from 14 July to 23 August. Fish collected at the dams were assumed to be emigrating. We selected 20 fish from a sample of fish passing through the dam's bypass system at the time of greatest passage, usually sunset. The fish were transported about 225 km from McNary Dam and 90 km from John Day Dam to the laboratory and transferred to the test flume. The same procedure used to transport and acclimate fish from McNary Pool was followed for fish collected at the dams.

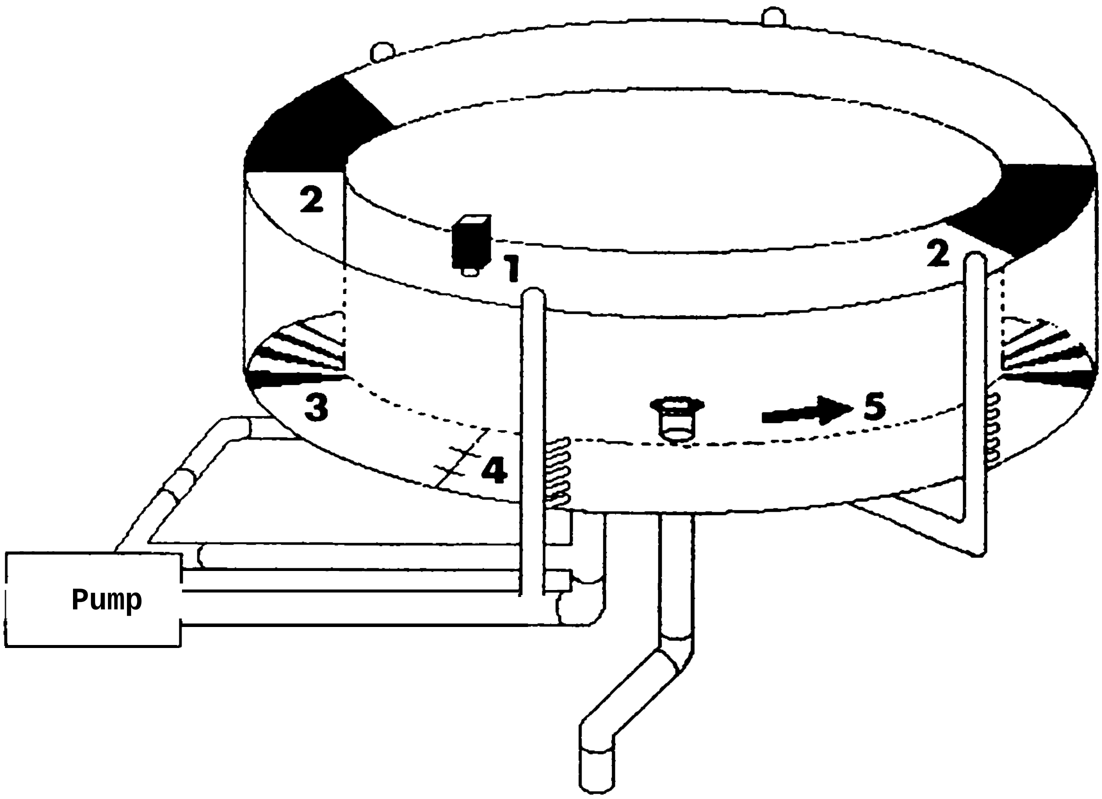
Incandescent lighting illuminated the test flume. A fixed photoperiod of 0500 to 2000 hours (15 h daylight, 9 h dark) was maintained throughout the testing period. Crepuscular lighting occurred twice a day for 1 h (0400 to 0500, 2000 to 2100 hours). The fixed photoperiod wa· used to ensure sufficient time for the fish to acclimate to complete darkness prior to the night swimming trials and to ensure complete darkness during the trials. Light intensity varied from l-4 lumens in the day and 0.02-0.07 lumens at night.

The test flume was supplied with well water which flowed through a 50 kW three phase single pass water heater. Water temperature was adjusted to follow the water temperature at the collection sites. During the testing period water temperature ranged from 11.5-18.3°C.

Laboratory Set-up

The test apparatus was a 36-cm wide by 35-cm deep circular flume located at the circumference of a 366-cm diameter fiberglass tank (Figure 1). A 7.5 horsepower pump connected to an adjustable frequency drive circulated water through 4 sets of 1.3-cm PVC pipes containing nine openings directed into the flume. Shade was provided by two covered 48.3 x 121.9-cm areas opposite from each other. Visual reference points were provided by two sets of six black lines about 5.0-cm wide and 7.6-cm apart painted on the flume bottom opposite from each other. An infrared sensitive camera was mounted above the flume, and an infrared light was used at night for illumination; reflective tape was placed beneath the camera on the flume bottom to increase available light. A black line painted across the reflective tape divided the flume into three equal sections denoting the inner, middle, and outer sections (Figure 1). This reference line was essential in counting the fish. A VHS record/playback machine and monitor were used to monitor and record fish behavior.

Water velocity was measured in the center of the flume. The velocity meter, monitor, and record/playback machine were located in an adjacent room to minimize disturbing the fish during tests.



l-camera
2-shaded areas
3-visualorientationlines
4-reference line
5-direction of water flow

Figure.l-An overview of the experimental design: the test tank and associated plumbinq.

Experimental Protocol

Identical swimming trials were conducted during the day and night. The night trials began after 1 h of darkness. The fish were subjected to progressively increasing water velocities of 5, 10, 15, 20, 25, 30, 40, and 50 cm/s in a 4 h period. Each velocity was maintained for 30 min; the first 15 min allowed the velocity to stabilize, and during the second 15 min the fish were videotaped. The day trials began 8 h after completion of the night trials. Upon completing the day trial the fork length, weight, and a gill sample were obtained from each fish. Gill Na^+,K^+-ATPase activity was measured according to Zaugg (1982).

Data Collection and Analysis

Five randomly selected 1.5 min intervals from each 15 min taping period were used to quantify the swimming velocity of the fish. The number of fish passing the reference line was counted. The orientation (i.e., swimming upstream-positive rheotaxis, swimming downstream-negative rheotaxis, and drifting) and distribution of the fish in the flume (i.e., inner, middle, and outer sections) were also recorded. The water velocity the fish experienced was estimated on the basis of their distribution in the flume, adjusting for a discrepancy in velocities of about 30% between the middle section and the inner and outer sections. The mean displacement velocity of the fish at each test velocity was calculated for each of the five counts at the eight velocities for a total of 40 observations per trial; mean swimming velocity of the fish was calculated by subtracting their displacement velocity from the water velocity. The swimming velocity of the fish was expressed in cm/s and body lengths per second (bl/s) to facilitate comparisons among different sized fish. Pearson's correlation coefficients and bivariate-regression analysis were used to examine relations between variables with Statgraphics software and multiple linear regression analysis was conducted using SAS software (SAS Institute 1988; Statgraphs 1992).

The hypothetical distance traveled by a fish in a 24-h period during each paired day-night series conducted was calculated as:

$$D = a\sum DVN_i + 2a\sum DVD_i;$$

where D = kilometers traveled per day, DVN = displacement velocity (cm/s) during night, DVD = displacement velocity (cm/s) during day, a = factor to convert cm/s to kilometers/8 h, and i = eight water velocity (cm/s) levels. The estimate was weighted on the basis of a 16-h day and 8-h night, which approximates the June-August photoperiod, and compared with the distance which would be traveled by passive drift at a water velocity of 24.4 cm/s, the mean of the eight water velocities to which the fish were subjected.

Results

Subyearling chinook salmon collected by beach seining in McNary Pool were tested five times from 7 May to 2 July, fish from McNary Dam were tested five times from 25 June to 21 August, and those from John Day Dam were tested four times from 15 July to 25 August (Table 1). Water temperatures during the trials increased from about 13°C in early May to nearly 19°C by July where they remained through August.

The mean fork length of subyearling chinook salmon sampled in McNary Pool nearly doubled during the collection period, increasing from 4.8 to 9.4 cm for a mean daily increase in fork length of 0.8 mm. The fish collected at McNary Dam exhibited less change in fork length, increasing from 10.7 to 12.7 cm, and fish collected at John Day Dam increased from 11.8 to 12.9 cm. Daily mean increase in fork length of the fish collected at McNary and John Day dams were 0.4 mm and 0.3 mm, respectively.

The level of gill ATPase activity in the fish sampled increased from 10.1 umol P_i/mg protein/h (units) in early May to 39.6 units in mid June and then decreased to 10.6 units in late August (Table 1). Gill ATPase activity of fish sampled in McNary Pool increased rapidly in June and averaged 20 units. The fish sampled at McNary Dam had levels of gill ATPase which were nearly twice the level of those sampled at John Day Dam, averaging 24.4 and 13.9 units, respectively.

Orientation and Distribution

Among the subyearling chinook salmon from the three sites, positive rheotaxis was the most common orientation observed (Table 2; Figure 2). Positive orientation was two times more common than negative orientation among fish collected at McNary Pool, nine times among fish collected at McNary Dam, and 21 times more common than negative orientation among fish collected at John Day Dam. Similarily, postive orientation was six times, 18 times, and 21 times more often observed than drift at McNary Pool, McNary Dam, and John Day Dam. Subyearling chinook salmon from McNary Pool and Dam exhibited significantly greater negative rheotaxis than drifting, but fish from John Day Dam did not exhibit any difference in the amount of negative rheotxis and drifting (Table 2).

The only tests during which fish exhibited significantly greater negative rheotaxis than positive rheotaxis or drifting was for fish collected in McNary Pool and tested on 21 May (Figure 2). These fish also exhibited negative rheotaxis at low water velocities, but only at 10 cm/s were the differences significant. In general, as water velocities increased the number of fish exhibiting positive rheotaxis increased (Figure 2).

Table 1. Date and water temperature (T) when experiments were conducted and the number (N), fork length (FL), weight (WT), gill $Na^{+}K^{+}$-ATPase activity level, and associated standard errors for the subyearling chinook salmon used in the experiments.

Date		T(°C)	N	FL(cm)		WT(g)		ATPase	
				McNary Pool					
May	7/8	13.2	20	4.8	(0.16)	1.0	(0.13)	10.1	(1.13)
May	21/22	11.5	20	5.2	(0.20)	1.3	(0.16)	11.2	(0.90)
June	4/5	16.2	19	6.7	(0.14)	2.7	(0.20)	14.1	(0.58)
June	18/19	15.1	18	8.4	(0.14)	5.8	(0.31)	39.6	(4.47)
July	1/2	18.6	17	9.4	(0.15)	8.4	(0.47)	24.9	(1.55)
				McNary Dam					
June	25/26	17.3	20	10.7	(0.14)	11.6	(0.49)	24.5	(2.19)
July	7/8	18.7	20	10.5	(0.10)	11.5	(0.41)	32.0	(1.63)
July	23/24	18.7	19	11.9	(0.17)	18.7	(1.00)	24.6	(1.79)
Aug	6/7	18.3	20	12.6	(0.23)	22.2	(1.36)	19.2	(1.65)
Aug	20/21	18.8	20	12.7	(0.13)	22.1	(0.74)	21.9	(1.45)
				John Day Dam					
July	15/16	18.7	20	11.8	(0.14)	15.8	(0.75)	12.4	(1.24)
July	30/31	18.4	20	12.2	(0.16)	18.2	(0.91)	17.4	(1.51)
Aug	13/14	18.5	20/18	12.5	(0.17)	20.1	(1.03)	15.2	(1.08)
Aug	24/25	18.3	18	12.9	(0.20)	22.7	(1.31)	10.6	(1.39)

Table 2. Paired Student's r-test of the mean number per minute of subyearling chinook salmon in each orientation and their lateral distribution in the flume when they crossed the reference line. Symbols next to the r-value indicate the level of significance: * = *P* c 0.05;** = PC 0.01.

		Orientation		
Orientation	Mean	Positive	Negative	Drift
		McNary Pool		
Positive	13.9		9.180**	17.114**
Negative	6.8			10.318**
Drift	2.3			
		McNary Dam		
Positive	11.3		20.471**	18.972**
Negative	1.2			3.688**
Drift	0.6			
		John Day Dam		
Positive	4.2		10.168**	10.289**
Negative	0.2			0.940
Drift	0.2			

		Distribution		
Distribution	Mean	Outer	Middle	Inner
		McNary Pool		
Outer	9.8		3.606**	14.848**
Middle	7.9			9.087**
Inner	3.6			
		McNary Dam		
Outer	4.0		2.860**	0.607
Middle	5.0			3.247**
Inner	3.8			
		John Day Dam		
Outer	1.1		3.142**	3.831**
Middle	1.6			1.267
Inner	2.0			

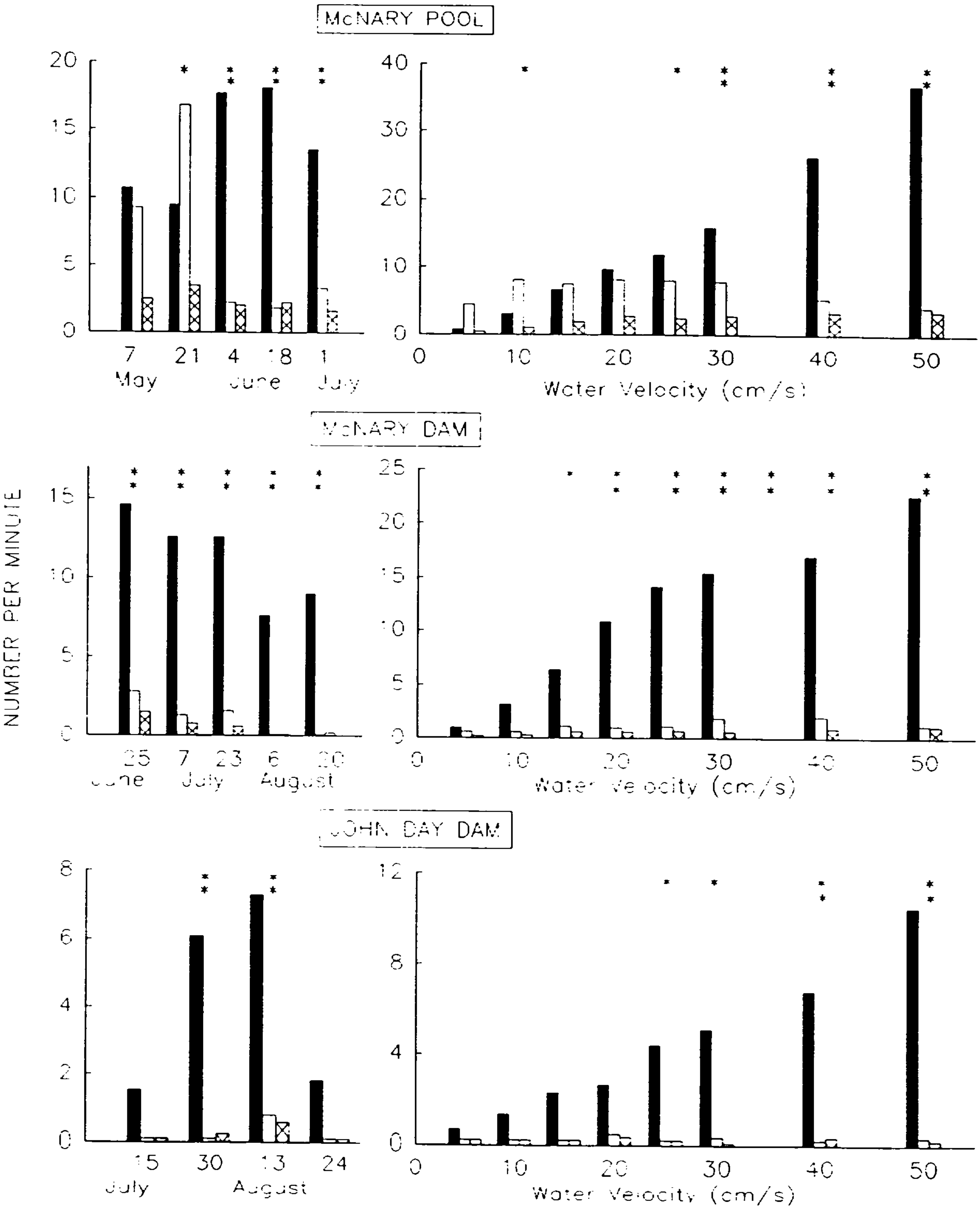


Figure 2. Number of subyearling chinook salmon per minute passing the reference line displaying positive rheotaxis (■), negative rheotaxis (□) or drifting (⊠) by date and water velocity. Significance of chi-square test of random orientation P < 0.05 =*, P < 0.01 = **.

The lateral distribution of the subyearling chinook salmon in the test flume tended to change from the outer section to the inner section, an area of lower water velocities, as the fish were collected further downstream and as test water velocity increased (Table 2; Figure 3). The mean number of subyearling chinook salmon per minute distributed in the outer, middle, and inner sections of the flume was significantly different between all three sections for fish collected at McNary Pool. The highest number of fish were counted in the fastest moving water in the outer section of the flume with lesser counts in the middle or inner sections. Similarly, significantly more fish from McNary Dam were counted in the middle section than in the inner or outer sections. Fish from John Day Dam were distributed with significantly more fish in the middle and inner sections than the outer section of the flume.

Swimming Velocity

In general, the swimming velocity of the subyearling chinook salmon increased with water velocity and time within and among collection locations (Figure 4). The swimming velocity of the fish tested was less variable at night than during the day (Figure 4). The maximum swimming velocity, 28 cm/s (5.9 bl/s), for McNary Pool fish was observed during the first night trial at a water velocity of 50 cm/s. Thereafter, fish from McNary Pool rarely swam at velocities > 12 cm/s (> 2 bl/s) at night and never attained 22 cm/s (3 bl/s). During the day trials in May, fish from McNary Pool swam downstream at velocities ≤ -10 cm/s (-2 bl/s) when the water velocities were ≤ 25 cm/s and they never attained swimming velocities of 10 cm/s (2 bl/s) at any water velocity tested. Fish tested during the day on 5 June swam at velocities equal to, or slightly higher than, water velocities when they were < 25 cm/s and then swam at < 5 cm/s (< 0.7 bl/s) at water velocities > 25 cm/s. In the day trials conducted on 19 June and 2 July, the fish exhibited the same behavior of swimming upstream at velocities sufficient to maintain their position until water velocities were > 30 or 40 cm/s, respectively, and then changed to swimming c 10 cm/s (< 1 bl/s) at higher water velocities.

Fish collected at McNary and John Day dams exhibited the general trend of increasing their swimming velocity with water velocity and date of the test (Figure 4). Bivariate regressions indicated water velocity explained 35% and 99% of the swimming velocity of fish collected at McNary and John Day dams respectively. Maximum swimming velocities of 42 cm/s (3.4 bl/s) at night and 59 cm/s (5.0 bl/s) during the day for McNary Dam fish and 47 cm/s (3.6 bl/s) at night and 54 cm/s (4.6 bl/s) during the day for John Day Dam fish occurred at water velocities of 50 cm/s. On 24 July, fish from McNary Dam tested during the day displayed the same behavior that had been observed for fish collected in McNary Pool; at a water velocity of 30 cm/s the fish

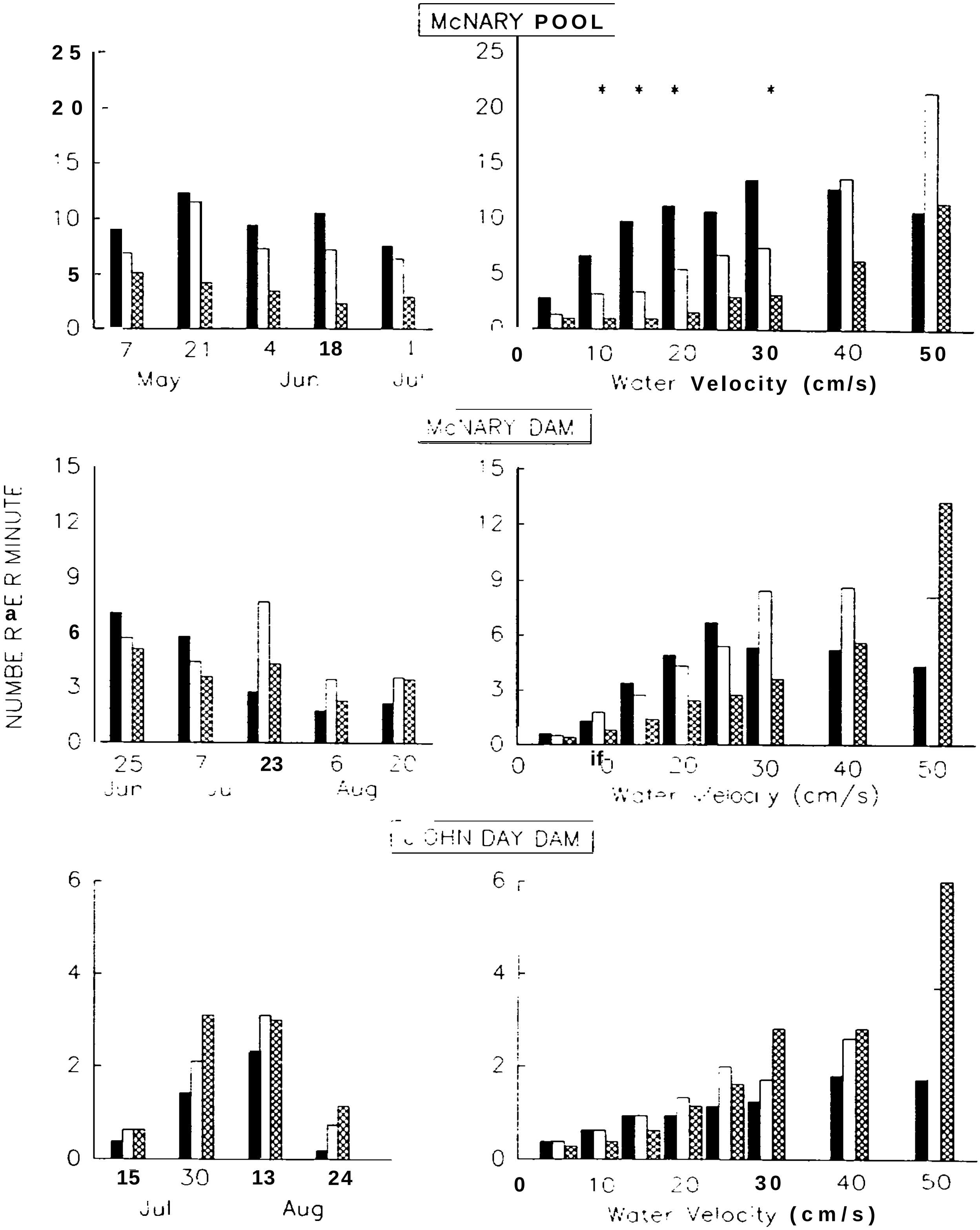


Figure 3. **Number of** subyearling **chinook** salmon **per** minute passing the **reference line distributed in** the outer (▆), middle (▭), **or inner** (▩) portions of **the** flume **by** date and water **velocity.** Significance **of** chi-square **test of random distribution** $P < 0.05 = *$.

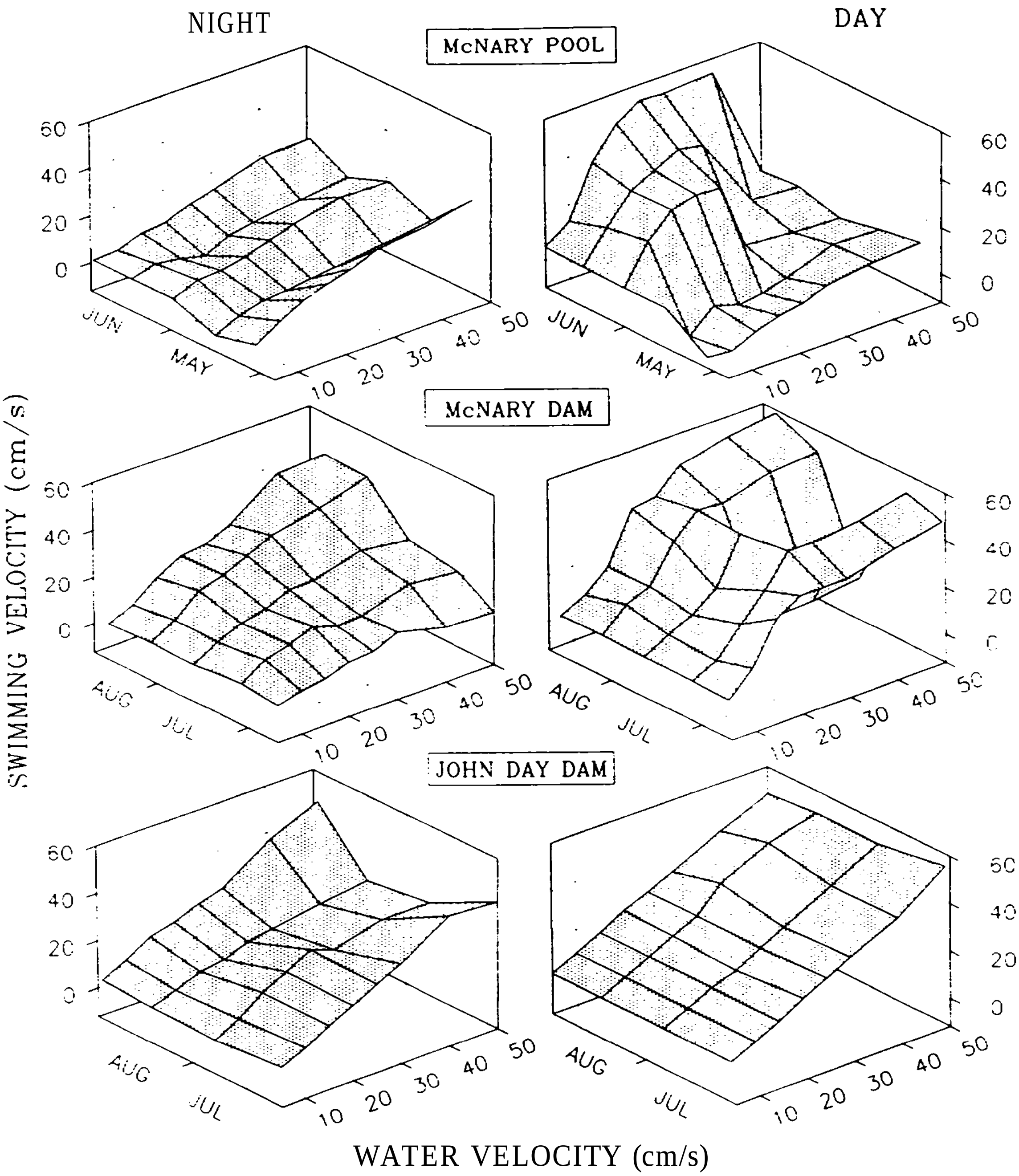


Figure 4. Swimming velocity of subyearling chinook salmon during the day and night at different water velocities by date and location of collection.

changed from swimming upstream at velocities necessary to maintain their position to swimming < 6 cm/s (< 0.5 bl/s) at water velocities > 30 cm/s.

The swimming performance observed for subyearling chinook salmon indicated they swam downstream primarily in May, during the day, at low water velocities. About 46% of the fish tested from McNary Pool during May were observed to swim downstream during the day, but < 3% of the fish from McNary Dam and none of the fish from John Day Dam exhibitited this behavior during the study. At night, about 16% of the fish tested during May from McNary Pool swam downstream, but none of the fish from McNary and John Day dams swam downstream throughout the season. Of the fish collected in May from McNary Pool which swam downstream, 85% of the observations during the day and all of the observations at night occurred at water velocities ≤ 25 cm/s.

Displacement

The mean day and night displacement rates for each test date from May through August were significantly correlated with water velocity used during the tests (Table 3). Downstream displacement rates in the test flume were negative early in the season during day and night, but neared zero displacement as day of the year, water temperature, and fork length increased throughout the season resulting in positive correlation coefficients with these variables (Table 3). Lunar phase and gill ATPase activity were not significantly correlated with mean displacement rates. The level of gill ATPase activity in fish sampled after 5 June was significantly correlated (r = -0.800; P < 0.01) with displacement rate at night and the day-night mean (r = -0.622, P < 0.01), but not during the day (r = -0.114; P > 0.05). In fact, deleting the 21-22 May results from the data set results in ATPase activity being significantly correlated (r = -0.614; P < 0.05) with displacement velocity at night.

Further analysis suggested the behavioral response to specific variables may have changed throughout the season, and as fish were collected from downstream dams. The coefficients of determination of bivariate regression models indicated that water velocity explained 75% of the variability in night displacement among fish collected from McNary Pool, 48% for fish from McNary Dam, and 34% for fish from John Day Dam (Figure 5). Displacement rates became increasingly negative at higher water velocities, resulting in an increased rate of downstream movement as water velocities increased (Figure 5). Water velocity did not explained the displacement velocity of fish tested during the day that were collected at McNary and John Day dams (P > 0.05). Fish collected at McNary and John Day dams and tested during the day tended to maintain their position, or swim upstream, over the range of water velocities tested; whereas fish tested at night

Table 3. Mean rate subyearling chinook salmon were displaced during the night and day for each test series and collection location correlated with environmental and biological **factors.** Correlation coefficient (r) with $P < 0.05$ = * and $P < 0.01$ = **.

		Displacement (cm/s)	
Date	Location	Night	Day
May 7, 8	McNary Pool	-10.8	-27.3
May 21, 22	McNary Pool	-23.5	-28.4
June 4, 5	McNary Pool	-16.6	-11.3
June 18, 19	McNary Pool	-23.9	-4.9
June 25, 26	McNary Dam	-16.2	4.3
July 1, 2	McNary Pool	-17.6	5.6
July 7, 8	McNary Dam	-12.3	7.1
July 15, 16	John Day Dam	-1.8	0.1
July 23, 24	McNary Dam	-9.2	-11.3
July 30, 31	John Day Dam	-6.3	1.0
August 6, 7	McNary Dam	-2.5	8.2
August 13, 14	John Day Dam	-11.7	0.4
August 20, 21	McNary Dam	-3.2	10.5
August 24, 25	John Day Dam	-0.9	0.9

Variable	Night	Day
Julian Date	0.703"	0.755**
Lunar Phase	-0.091	-0.077
Water Velocity	-0.666"	-0.356"
Water Temperature	0.623'	0.863"
Fork Length	0.699**	0.811"
ATPase Activity	-0.363	0.428

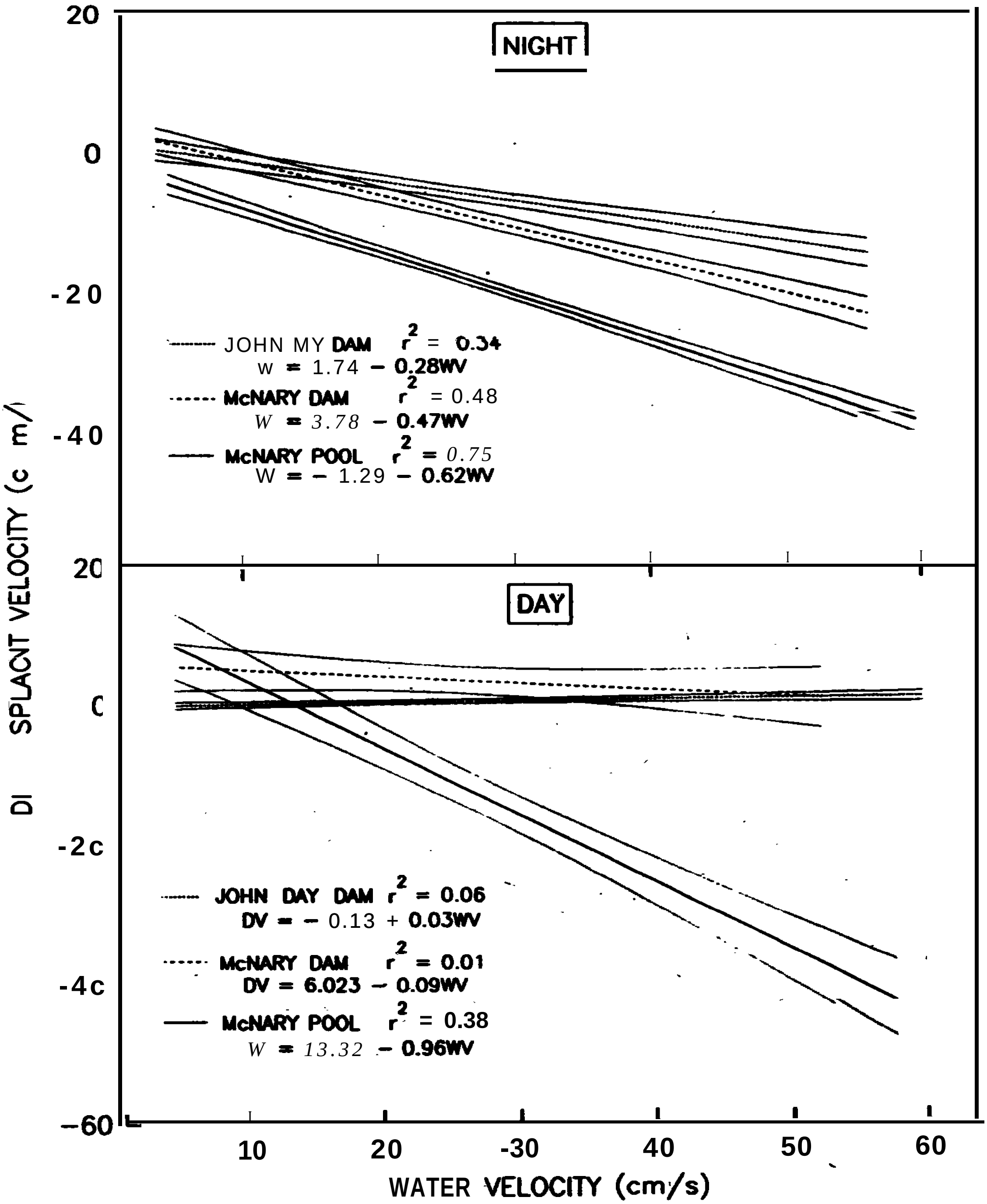


Figure 5. Relationship between displacement velocity of subyearling chinook salmon collected at different locations and the water velocity and time of day tested.

were displaced, albeit slowly, when water velocities exceeded about 10 cm/s.

Multiple regression models explained 92% of the variablility in displacement of subyearling chinook salmon from McNary Pool, 76% for fish from McNary Dam, and 70% for fish from John Day Dam (Table 4). Displacement rates were analyzed by day and night for each location because multiple regression analysis did not identify any significant independent variables to predict fish displacement during the day among fish collected from McNary and John Day dams ($P > 0.05$). The stepwise regression routine selected water velocity first to explain displacement of fish during the daytime flume tests for fish collected at McNary Pool and for all night tests for fish collected at McNary Pool, McNary Dam, and John Day Dam.

Other variables entering the final multiple regression models of displacement rates included water temperature, fork length, gill ATPase, and a variable related to lunar phase (moon). Day of the year, weight, and a second variable related to moon phase were removed from the analysis because multicollinearity diagnostics indicated problems in the models. Inclusion of water temperature, fork length, and gill ATPase in the same model usually resulted in multicollinearity. The final model we selected to predict displacement among fish collected at John Day Dam included water velocity, gill ATPase, and number of days from the last new moon and had an R^2 = 0.697 (Table 4). A model using a logrithm transformation of displacement rate included water velocity, gill ATPase, the number of days to the nearest new moon, and fork length. The model using the logrithm transformed displacement values increased the R^2 to 0.779, improved the Mallow's C, and improved the multicollinearity diagnostics. However, we did not select that model because the increase in R^2 were not great, and interpretation of the biological significance was difficult.

In response to these displacement rates, the extrapolated distance a subyearling chinook salmon would be carried downstream in 24 h progressively decreased with time (Figure 6). At the mean test water velocity of 24.4 cm/s, drifting in the current would carry an object 21 km in 24 h. The extrapolated distance a fish would move in an 8-h night ranged from 0.2 to 7 km downstream. During a 16-h day the distance was more variable, ranging from 16 km downstream to 6 km upstream. With the exception of fish collected at McNary Dam and tested on 23 and 24 July, the subyearling chinook salmon tested after 25 June would theoretically move downstream about 3 km/24 h if the mean water velocity was 24.4 cm/s (Figure 6). The reason the fish tested on 23 and 24 July moved downstream farther than other fish tested during this period was because the fish tested during the day swam < 6 cm/s after the water velocity > 30 cm/s rather than

Table 4.-Multiple-regression models for predicting displacement of subyearling chinook salmon in a swim flume during day and night.

Location	N	Variable	Coefficient	P	Beta Coefficient	Partial R^2	R^2
			Day				
McNary Pool							
	40	Constant	-36.069	0.0006			0.681
		Velocity	-0.954	0.0001	-0.620	0.391	
		Length	7.143	0.0001	0.539	0.290	
McNary Dam							
	40			NS			
John Day Dam							
	32			NS			
			Night				
McNary Pool							
	40	Constant	20.625	0.0001			
		Velocity	-0.610	0.0001	-0.857	0.770	0.919
		Moon	-0.701	0.0001	-0.507	0.117	
		Temperature	-1.056	0.0006	-0.243	0.032	
McNary Dam							
	40	Constant	-52.862	0.0001			
		Velocity	-0.464	0.0001	-0.690	0.493	0.758
		Length	5.186	0.0001	0.490	0.229	
		Moon	-0.239	0.0260	-0.191	0.036	
John Day Dam							
	32	Constant	67.838	0.0001			
		Velocity	-0.276	0.0001	-0.585	0.356	0.697
		ATPase	-3.888	0.0001	-1.505	0.188	
		Moon	-0.866	0.0008	-1.141	0.154	

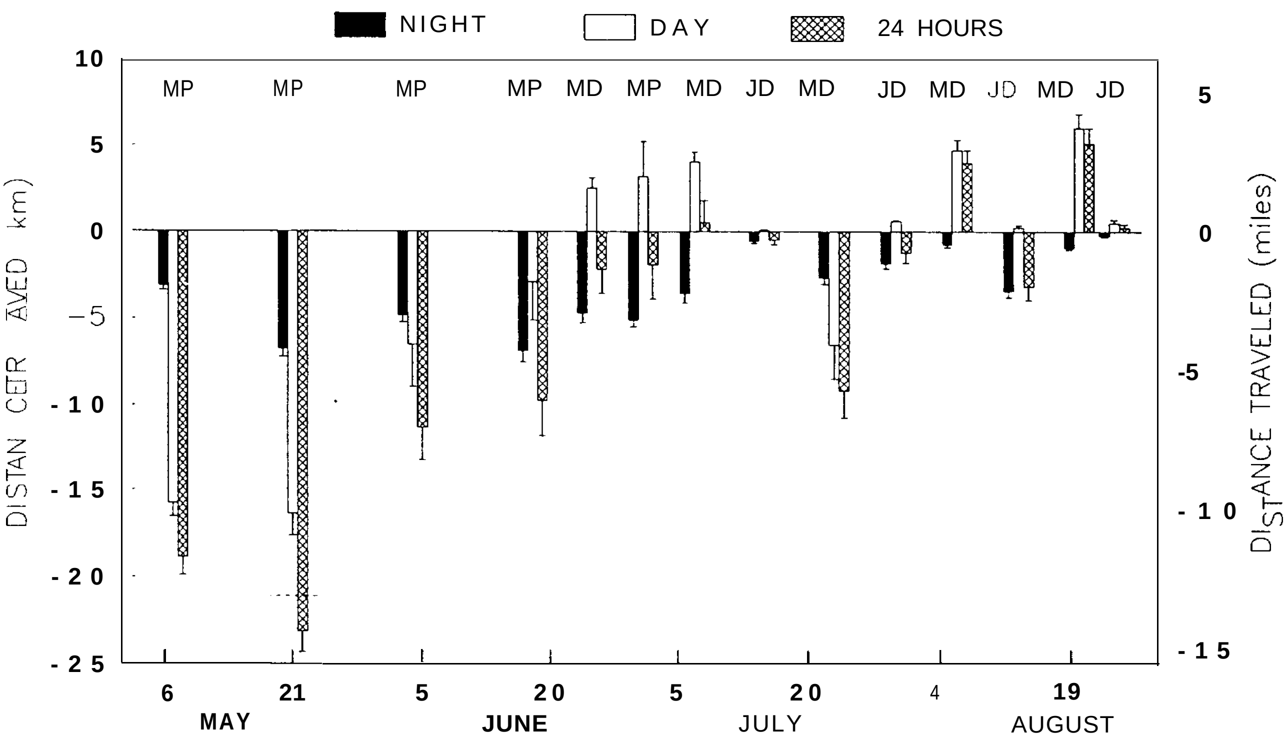


Figure 6.– Hypothetical mean (and SE) distance a subyearling chinook salmon collected at McNary Pool (MP), McNary Dam (MD), and John Day Dam (JD) would travel during an 8-h night, 16-h day, and 24-h period. The dashed line indicates the distance traveled in 24 h by passive drift at the mean water velocity tested.

swimming at velocities similar to the water as did the other fish tested (Figure 4).

Discussion

The test conditions and origin of fish used in the swimming trials were selected to represent as closely as possible conditions that the stock of fall chinook salmon originating from the Snake River are exposed to during their rearing and emigration. The range in test water velocities from 5 to 50 cm/s are representative of water particle travel times which would result from discharges of about 12 to 124 KCFS (thousands of cubic feet per second) from Lower Granite Dam and 44 to 443 KCFS from John Day Dam. Water temperatures during the swimming trials were maintained as closely as possible to ambient Columbia River water temperatures. Collection of subyearling chinook salmon in McNary Pool and at McNary and John Day dams provided fish covering a wide range in development. The fish sampled over the nearly four months of the study differed by as much as 8 cm in mean length, 21 g in mean weight, and nearly 30 units in mean gill ATPase activity. The fish sampled at McNary and John Day dams increased less in length than did the fish collected in McNary Pool. The greater length (1-2 cm) of fish captured from mid-June to early July at McNary Dam than in McNary Pool would indicate that larger fish in the population were emigrating from the reservoir.

Subyearling chinook salmon predominately swam upstream at rates comparable to the water velocity, thereby maintaining their position in the flume. Displacement downstream occurred during periods when at all water velocities the fish reduced their swimming velocity to 5-15 cm/s (0.5-1.5 bl/s), rates only sufficient to maintain their equilibrium in the current. Trump and Leggett (1980) estimated the optimum swimming speed in terms of energetic costs of fish migrating in currents would be about 1 bl/s. During all swimming trials the fish rarely drifted without locomotion in the water column, perhaps while not swimming they lose body control and the ability to rapidly move to capture food or evade predators.

Fish were observed to swim downstream only at water velocities c 15 cm/s on 21 May, the period of their maximum displacement (Figures 2, 4). This behavioral response would be a logical evolutionary development to ensure emigrating fish swept into eddies or backwaters would return to higher velocity areas of the main channel. In addition, fish selected the highest water velocity in the outer section of the flume during the period when they were displaced the farthest, and were distributed in the inner section in the slower water when they exhibited minimal displacement (Figure 3).

Throughout the study fish tended to swim slower, and more consistently, during the night than during the day (Figures 4, 5). This swimming performance resulted in the fish being displaced farther downstream in an 8 h night than a 16 h day on 10 of the 14 trials as would be expected for chinook salmon which are considered nocturnal migrants (Healey 1991). However, during four daytime tests the fish exhibited swimming behavior which, if repeated in the reservoirs, would result in greater displacement during the day than at night. The fish collected in McNary Pool during May exhibited the greatest potential displacement of all the fish tested because during the day they swam slowly at all water velocities (Figures 4, 6). Conversely, fish collected at McNary Dam during August exhibited a potential net upstream movement because during the day their swimming velocity exceeded the water velocity. This swimming behavior observed in the laboratory would result in a long residence time in John Day Pool unless the mean water velocity (i.e., water particle travel time) exceeded about 24 cm/s (equivalent to a discharge rate of 216 KCFS at John Day Dam) and explains the reported recovery of marked fish upstream from their release location in this reservoir (Giorgi et al. 1990).

With the exception of subyearling chinook salmon tested on 21-22 May, the fish were never displaced downstream as far as they would be by drifting with the current (Figure 6). Fish on 21-22 May exceeded the theoretical distance traveled by drifting because they actively swam downstream during the day when the water velocities were ≤ 25 cm/s (Figures 2 and 4). The observation that fish usually swam upstream explains why regression analysis of juvenile chinook salmon travel time on water velocity is always less than water particle travel time (Beeman et al. 1991; Buettner and Nelson 1992; Berggren and Filardo 1993). Our laboratory data indicates that only when fish were confronted with very low water velocities, during the time of their maximum disposition to migrate, would they actively swim downstream and exhibit travel times exceeding water particle travel time.

During some daytime tests the fish changed their behavior as the water velocities increased from swimming upstream at velocities comparable to the water velocity to swimming at velocities only sufficient to maintain their equilibrium (Figure 4). The water velocity at which this change in performance occurred increased from 25 cm/s on 5 June to 40 cm/s on 2 July for fish from McNary Pool and at 30 cm/s on 24 July for fish from McNary Dam (Figure 4). Increases in water velocities at which the fish maintain position, or move upstream, during the day indicate a decrease in disposition to emigrate and significantly influences the distance a fish would be displaced downstream, i.e., the higher the water velocities the fish maintain their position in the less they will be displaced (Figure 6). This same change in day time swimming performance was observed at water velocities ≥ 30 cm/s in June 1991 for subyearling chinook salmon collected at Bonneville Dam (Nelson et al. 1993).

The change in swimming performance at water velocities of 25 to 40 cm/s could be caused by fatigue or a change in behavior. Studies on various species, including salmonids, have indicated that the fish should not have become fatigued by the velocities in the length of time they were tested (Bainbridge 1962; Brett 1967; Beamish 1978;). During the tests conducted the night prior to the day trials, the same fish progressively increased their swimming velocities to > 20 cm/s as the water velocity increased, whereas during the day they abruptly changed their performance from swimming at velocities > 40 cm/s to swimming c 10 cm/s (Figure 4). Irvine (1986) observed that the number of chinook salmon fry emigrating from experimental streams in New Zealand increased when water velocities exceeded 25 cm/s and Ottaway and Clarke (1981) estimated that water velocities of 26.5 to 42.5 cm/s increased the downstream movement of brown trout *Salmo trutta*. Therefore, it appears that as water velocities exceed threshold levels of 25-40 cm/s, fish may change their behavior from holding position to emigrating, with the threshold water velocity increasing as fish lose their disposition to emigrate.

Subyearling chinook salmon exhibited their greatest disposition to emigrate during May and June when they were < 90 cm long (Figure 6, Table 1). In the Sacramento-San Joaquin, California and Situk, Alaska rivers, the southern and northern range limits of fall chinook salmon, the peak of emigration occurs from April to June and July to August (Kjelson et al. 1982; Johnson et al. 1992). Subyearling chinook salmon in the above rivers, and from others on the Pacific Coast, migrate seaward when they are 70-80 cm in length (Healey 1980; Healey and Groot 1987; Healey 19911.

The rate at which fish in this study were displaced was significantly correlated with water velocity (i.e., the downstream displacement rates became increasingly negative as water velocity increased; Table 3). Studies by Berggren and Filardo (1993) demonstrated the time subyearling chinook salmon took to migrate between two locations in a reach decreased as river flow increased. Displacement rates were positively correlated with other variables, indicating less downstream displacement with later dates, higher water temperature, and increasing fish lengths (Table 3). **Various studies of other species of salmonids have shown that an increase in size and** water temperature increases the fishes' swimming performance (Brett 1967; Beamish 1978). Therefore, the observed decrease in **subyearling chinook salmon displacement caused by their increased** swimming performance should be expected as their length and the **water temperature** increased during the study.

Lunar phase and gill ATPase activity were related to displacement rate, but the relation was not as simple as other independent variables. Lunar phase has been reported to influence emigration rate of other salmonids (Grau 1982). Lunar variables were not significantly correlated with average displacement rates, but were significant independent variables in multiple regression models predicting displacement during night at specific water velocities. Beeman et al. (1991) reported the level of gill ATPase activity was significantly correlated with the travel time of yearling chinook salmon. We found maximum displacement occurred during May and June when gill ATPase activity was increasing and minimal displacement occurred as gill ATPase declined later in the season.

In summary, subyearling chinook salmon were displaced most rapidly during May and June when they were less than 9 cm in length and the water temperature was less than 16°C. During displacement the fish swim upstream at about the optimum velocity of 1 bl/s, or just fast enough to maintain body control. Rate of displacement was normally equal to water velocity minus the swimming velocity of about 1 bl/s so the higher the water velocity the more rapidly the fish were transported downstream. During the peak of emigration, fish are capable of moving substantial distances during the day as well as at night, the time when they usually are displaced the farthest. Fish actively swam downstream only at very low water velocities, when their disposition to migrate was maximum, and rarely drifted in the current.

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CHAPTER FOUR

Evaluation of PIT Tagging of Subyearling Fall Chinook Salmon During 1991 and 1992

by

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Introduction

Subyearling chinook salmon *Oncorhynchus tshawytscha* naturally produced in the Hells Canyon Reach of the Snake River were tagged with passive integrated transponders (PIT) and recaptured at Lower Granite Dam to record time of emigration (Connor et al. 1993). **PIT** tags are ideal for these studies because they mark each fish uniquely so that individual fish can be monitored. Also, because they are internally planted, the hydrodynamics, camouflage coloration, and fins of fish are not affected. However, because the goal of this tagging was to better understand factors affecting their emigration, it was important to determine what effects tagging would have on subyearling chinook salmon behavior and survival. If PIT tagging significantly altered behavior, especially migratory behavior, then conclusions about their emigration drawn from PIT-tag recapture data could be erroneous. Furthermore, survival of tagged fish was a concern because the Snake River fall chinook salmon stock had declined to such low numbers it was being considered for listing under the Endangered Species Act in 1991 and was listed as threatened in 1992. Tagging fish from this threatened population would be unacceptable if it caused high mortality.

Connor et al. (1993) anticipated that subyearling chinook salmon ranging from 55 mm to 70 mm would be readily captured by seine in nearshore habitats downstream from spawning areas in the Hells Canyon reach and, conversely, that larger fish would be widely dispersed in deeper habitats requiring large traps or weirs for capture. Therefore, if adequate numbers were to be tagged it would be necessary to implant tags in fish **as** small as 55 mm to 65 mm fork length. The direct or delayed mortality associated with the small size of fish we would be tagging and the possible aberrant migratory behavior following release were of concern to us as we prepared for the first year of this study. Therefore, we conducted a series of laboratory tests prior to field tagging.

During the development of PIT tags for use in juvenile salmonids considerable information was collected on the behavior and survival of fish after tagging (Prentice et al. 1990a). They measured growth, survival, and PIT-tag retention for subyearling chinook salmon with mean fork lengths ranging from 66 mm to 100 mm; survival ranged from 95 to 100% for about 135 d. Less than 12% mortality 45 d after tagging **was** reported for **juvenile** steelhead *O. mykiss* with mean fork lengths 80 mm to 129 mm (Prentice et al. 1986).

Although the results of Prentice et al. (1990a) did not demonstrate a relationship between fish size and tagging mortality rate or tag retention rate, the fish we would be tagging were smaller than those other investigators had tested. Because PIT tags are 12 mm long, we anticipated there would be a minimum fish size below which tagging would be lethal and that limit had not been determined.

In addition to delayed mortality following tagging, swimming performance and vulnerability to predation were of concern. During development and testing of the tag neither the tagging procedure nor the presence of the tag in the fish was found to have a significant effect on swimming performance (Prentice et al. 1990a). The mean lengths of subyearling chinook salmon Prentice et al. (1990a) tested was 67 mm and 89 mm, considerably larger than the fish we were considering PIT tagging. Therefore, we added swimming performance to our premarking tests.

The purpose of these experiments was to (1) quantify the effects of PIT-tagging procedures on the survival of 55 mm to 70 mm subyearling chinook salmon, (2) evaluate swimming stamina as an indication of physical condition of the fish, and (3) evaluate the effects tagging had on complex behavior; in this case predator avoidance. This paper reports the results of experiments started in 1991 and completed in 1992.

Methods

All subyearling fall chinook salmon used in these experiments were of the upriver bright stock obtained from Little White Salmon National Fish Hatchery. The upriver bright stock of fall chinook salmon was selected as **a** surrogate experimental animal for the Snake River stock because they are closely related and were readily available. Experiments were conducted in 1991 and 1992. Methods varied from the first year to the second.

In preparation for tagging, fish were netted from a holding tank and placed in **a** bucket of water containing 26 mg/L tricaine methanesulfonate (MS-222) anesthetic. In 1991, ten to 15 fish were anesthetized at a time while in 1992 only 6 to 8 fish were anesthetized at **a** time. Also in 1992, the anesthetic solution contained 0.1 g salt, 3.5 g baking soda and 1 ml of polyproaqua (synthetic slime) per 3.8 L of water. Prior to tagging fish were removed from the bucket and weighed and measured. Fish were then held for tag insertion in a slit on a sponge. PIT tags used in these experiments were approximately 12 **mm** in length and 2 mm in diameter. Each PIT tag was inserted into a 12 gauge hypodermic needle prior to tagging. The needle was inserted into the fish so that the bevelled tip completely penetrated beneath the surface of the skin at a point on the midline of the ventral surface posterior to the pectoral fins. The tag was pushed out of the needle so it was positioned just beneath the skin anterior of the wound. Then the needle was backed out of the wound and the wound was swabbed with disinfectant. The fish was placed in aerated water to revive it from the anesthetic. These operations constituted the act of PIT tagging the fish and use of the word tagging in this paper refers to this process. Each fish required approximately 1 min and 30 s to tag after removal from the anesthetic; including weighing and measuring. In each type of test described below, PIT-tagged fish are referred to as treatment fish and fish without tags are controls.

Predation Vulnerability

The primary measure of relative performance in the predation vulnerability experiment was the number of treatment and control subyearling chinook salmon that were consumed by the predator, smallmouth bass *Micropterus dolomieue*. Treatment and control groups were simultaneously introduced into a tank holding four smallmouth bass and exposed to predation risk for 24 h. Tanks in which the experiments were done measured 1.2 m in diameter. Four segments of 20 cm diameter polyvinyl chloride pipe were placed in each tank to provide structural diversity and cover. Water temperature in the tanks was 10°C. In 1991, groups of treatment and control fish were allowed either 0.5 h or 96 h recovery time prior to predation exposure while in 1992, fish were allowed 0.5 h, 4 h, or 24 h recovery. Control fish were held under the same conditions as treatment fish before introduction into tanks where experiments were conducted. Subyearling chinook salmon used in 1991 predation experiments ranged in fork length from 48 mm to 73 mm with a 59 mm mean fork length. In 1992, fork lengths ranged from 60 mm to 74 mm with a 64 mm mean. Smallmouth bass chosen randomly from a holding tank were given at least 24 h to acclimate to the tanks prior to introducing subyearling chinook salmon. Smallmouth bass were not fed during the acclimation period. Smallmouth bass fork length ranged from 199 mm to 268 mm; weight ranged from 111 g to 242 g. At the beginning of each predation experiment 32 treatment and 32 control fish were simultaneously introduced into the tank. After 24 h all survivors were removed, weighed, measured, and identified as treatment or control fish by examining their ventral surface for insertion scar and scanning with a PIT-tag detector (Prentice et al. 1990b). Predators were also weighed and measured at the end of each 24 h test. Three replicates of the predation experiment were conducted for 0.5 h and 96 h recovery groups in each of the trials that started 10 May and 17 May 1991. In 1992, three replicates of each experiment were also conducted for 0.5 h, 4 h, and 24 h recovery groups during each of the trials that began 4 May and 11 May 1992.

Chi-square goodness of fit tests were used to compare the number of treatment and control fish eaten to the expected number eaten in each group within each tank. The null hypothesis was that prey selection by smallmouth bass did not vary from random feeding. Alternatively, the hypothesis was stated as an expression of prey vulnerability; treatment or control fish were not consumed in greater numbers than their relative proportion in the tank; 0.5 h, 4 h, 24 h, and 96 h recovery tests were analyzed separately. Chi-square heterogeneity tests were applied to data for all tanks of a recovery group to test whether the proportion of treatment and control fish eaten varied among tanks. Where heterogeneity was not significant, data from all tanks of that recovery period were pooled and an overall chi-square test used. Size 'selectivity of treatment fish by predators was tested using a Kolmogorov-Smirnov test; the cumulative length frequency distribution of surviving treatment fish was compared to that of treatment fish initially introduced into the tanks.

We also conducted tests to compare the vulnerability of sham-tagged fish to control fish. Fish were sham tagged by inserting the tag injection needle into their abdomen without inserting a PIT tag. Equal groups of 32 sham-tagged fish and 32 controls were subject to predation as described for other predation tests. Results were analyzed using chi-square tests to determine if predators were selectively depredating sham or control fish as was done for the PIT-tag tests.

Swimming Stamina

Swimming stamina of subyearling chinook salmon was estimated using a Blazka respirometer (Blazka et al. 1960). Swimming stamina was determined after fish were allowed a post-tagging recovery period. In 1991, recovery periods were 0.5, 4, 24, 48, or 96 h while in 1992, they were 0.5, 4, or 24 h. After recovery, six fish were selected randomly from control and treatment fish holding tanks. Fish from each group were placed in two separate compartments of a swim chamber. To keep track of individual fish, each was identified by unique natural markings, such as parr marks.

The swim chamber was calibrated prior to testing by placing a Marsh-McBirney water velocity meter in the swim chamber to measure water velocity. Water flow was generated by an impeller at the rear end of the swim chamber which was turned by a variable speed electric motor. Impeller turning speed was measured by a tachometer. A plot was generated of flow velocities measured by the flow meter in the swim chamber and the revolutions per second of the impeller. The tachometer was then used during the course of the swim tests to indicate water velocity in the swim chamber.

An electrified grid at the downstream end of the swim chamber was used to stimulate fish to swim to exhaustion. Black plastic was wrapped around the central portion of the swim chamber and the downstream end of the chamber was illuminated with a 100 W light to discourage fish from seeking refuge from velocity in front of the electrified grid.

Fish were given 0.5 h to acclimate in the swim chamber before testing began. Those fish held for the 0.5 h recovery period were placed in the swim chamber immediately after tagging and allowed to acclimate. During the first replicate of swim performance tests, in 1991, water temperatures at the end of the swim tests were 13° to 14°C due to low volume of water circulation. Water temperature during the second replicate of swim tests was held between 10.4° and 11.6°C by circulating fresh water through the chamber. Water temperatures for the 1992 swim tests were held between 10.0° and 11.0°C. Water velocity for each swim test began at 1.5 body lengths per second (bl/s) and was increased 0.5 bl/s every 15 min. One body length was defined as 60 mm although fish ranged in length from 49 mm to 63 mm. Tests were continued until all fish were fatigued. A fish was considered fatigued when it lodged against the grid.

Time of fatigue, U-critical, was calculated for each fish using the following formula from Beamish (1978) :
U-critical = $U_i + (t_i/t_{ii} * U_{ii})$; where, U_i = highest velocity increment during which fish was not fatigued, U_{ii} = velocity increment (0.5 bl/s), t_i = time (min) fish swam during final increment, and t_{ii} = time period of each increment (15 min).

A general linear model analysis of variance (ANOVA) was used to analyze the importance of tagging and recovery period on swim performance. The general linear model was used because of the unbalanced design of the experiment (SAS 1988). Three other variables, chamber position, experimental replicate, and fork length, were included in the analysis to determine what effects each had upon the swim test results. Mean U-criticals for treatment and control groups in each trial were also compared using the Tukey method for t-tests to further analyze the importance of recovery period for each trial.

Tag Retention and Dalayed Mortality

Treatment and control subyearling chinook salmon were held in separate 0.5 m diameter tanks for 96 h after tagging to assess mortality. Water temperature in the tanks was 10°C. Two groups of 40 fish were anesthetized and tagged and then held in separate tanks. Two groups of 40 control fish were also held in separate tanks identical to those holding the tagged fish. Fish were not fed during the 96 h they were held. In the first trial, the mean fork length of treatment fish was 57 mm compared to 55 mm for the control fish. During the second trial, mean fork length of treatment fish was 63 mm and the mean fork length of control fish was 60 mm. Tanks were checked 24, 48, 72, and 96 h after PIT tagging. All dead fish were removed, counted, weighed, and measured. Fish from the treatment groups were examined for tags. At the end of 96 h all fish were removed from the tanks, weighed, measured, and treatment fish checked for tag retention.

Longterm Growth

During 1992 laboratory experiments, we conducted a series of trials in which subyearling chinook salmon of the upriver bright stock were tagged and held for 44 d. The tagging protocol was the same as used for the 1992 experiments described here. Groups of 100 treatment fish and 100 control fish were held in each of 3 rearing tanks. The arbitrary size groups were small fish (50 mm to 59 mm FL); middle (60 mm to 69 mm FL); and large (70 mm to 79 mm FL). At the outset of the trials the mean fork length of control groups were 56, 65, and 72 mm while treatment groups were 56, 64, and 72 mm. The fish were stocked into tanks according to size group on 13 May, and 50 fish from each tag group were weighed and measured on 4 June, 25 June, and 28 July. Mean fork length of treatment and control groups was compared for each measurement period within each tank using the Tukey method of comparison (SAS 1988).

Results

Predation Vulnerability

During the 1991 0.5 h recovery tests, smallmouth bass consumed a larger proportion of treatment fish than control fish in all tanks (Figure 1). The heterogeneity chi-square test comparing the proportion of treatment and control fish eaten in all tanks was not significant for the 0.5 h recovery tests. Therefore, data were pooled from all six tanks of the 0.5 h recovery replicates and the pooled chi-square calculated (Sokal and Rohlf 1981). The pooled chi-square was significant indicating that a greater proportion of treatment fish were eaten than would be expected if predation was random. Additionally, individual chi-square tests for three of the six 0.5 h recovery tanks showed a significant difference in the number of treatment and control fish that were eaten (Table 1).

During 1991 tests, when the subyearling chinook salmon were allowed 96 h to recover prior to the predation test, there was no significant trend in feeding selectivity by smallmouth bass for either treatment or control fish (Figure 1). The chi-square test for heterogeneity was significant so that pooling the data for all six 96 h predation tanks was not appropriate. The number of treatment and control fish eaten was not significantly different in any tank of either trial one or trial two (Table 2). In 1992

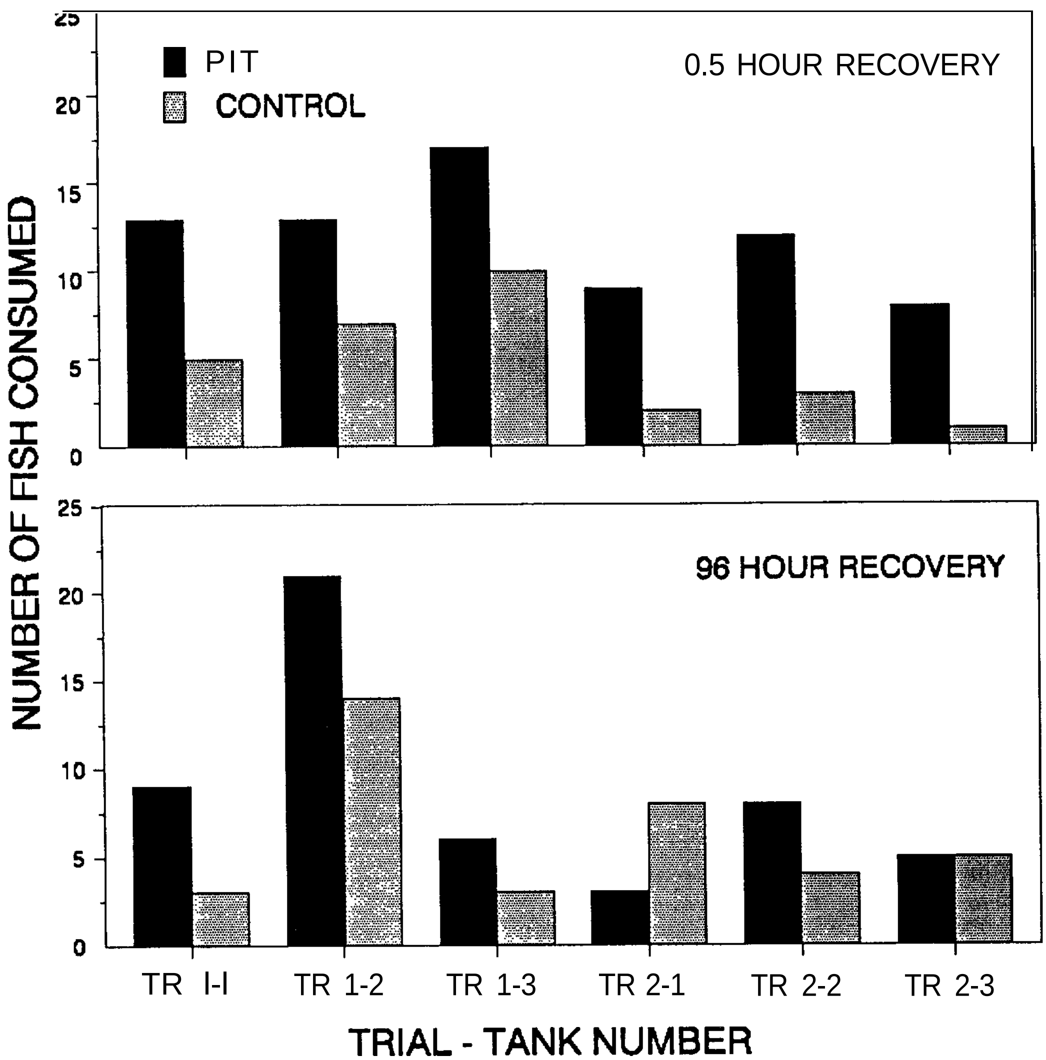

Figure 1.-Total number of juvenile chinook salmon eaten in 1991 predation vulnerability trials. Trials begun on 10 May and 17 May are shown separately as are individual tanks (1,2, and 3) in which tests were conducted. The two recovery periods, 0.5 h and 96 h, are included for comparison.

Table l.-Results of predation risk experiments conducted in 1991 in which PIT-tagged juvenile fall chinook salmon allowed 0.5 hour recovery and controls were exposed to 24 hour predation risk by smallmouth bass.

Tag	Exp#-tank#	Number eaten	Expected# eaten	Chi-square	P-value
PIT	l-l	13	9.0	3.556	0.056
Control		5			
PIT	1-2	13	10.0	1.800	0.176
Control		7			
PIT	l-3	17	13.5	1.836	0.174
Control		10			
PIT	2-l	9	5.5	4.455	0.033
Control		2			
PIT	2-2	12	7.5	5.400	0.016
Control		3			
PIT	2-3	8	4.5	5.440	0.019
Control		1			
PIT	Pooled	72	50.0	19.360	0.00002
Control		28			
Total				22.469	0.0005

Table 2.-Results of predation risk experiments conducted in 1991 in which PIT-tagged juvenile fall chinook salmon allowed 96 hour recovery and controls were exposed to 24 hour predation risk by smallmouth bass.

Tag	Exp#-tank#	Number eaten	Expected# eaten	Chi-square	P-value
PIT	1-l	9	6.0	3.000	0.080
Control		3			
PIT	l-2	21	17.5	1.400	0.235
Control		14			
PIT	l-3	6	4.5	1.000	0.681
Control		3			
PIT	2-l	3	5.5	2.273	0.127
Control		8			
PIT	2-2	8	6.0	1.333	0.247
Control		4			
PIT	2-3	5	5.0	0.000	1.000
Control		5			
PIT	Pooled	52	44.5	2.528	0.107
Control		37			
Total				9.006	0.1087

predation tests, there were no significant trends in the relative vulnerability to predation of treatment versus control fish (Figure 2). Predation vulnerability was not significantly different in any single tank (Tables 3, 4, and 5).

Results of the 1991 and 1992 sham-tag tests also showed no significant trend in selectivity by smallmouth bass (Figure 3). In 1991, the 0.5 h recovery period chi-square values comparing treatment and control fish showed no significant difference in any trial. In tank four, 16 treatment fish and 8 control fish were eaten and in tank five 8 treatment fish and 7 control fish were consumed. The heterogeneity chi-square was significant, therefore the data for the two tanks were not pooled. For the 96 h recovery period tests, 5 treatment and 5 control fish were eaten in tank 4, while 2 treatment fish and 4 control fish were eaten in tank 5. The heterogeneity chi-square was significant so that data was not pooled. In 1992, the 0.5 h recovery period comparison of sham and control showed no significant difference in four tests. The numbers of treatment to control fish eaten in four seperate tanks were 9 sham tag to 12 control; 13 sham tag to 15 control; 8 sham tag to 7 control; and 13 sham tag to 9 control. Heterogeneity chi-square was not significant so data from all four tanks were pooled. The total chi-square (0.000) was not significant (P = 1.000).

For 1991 experiments, a comparison of mean fork lengths of all PIT-tagged fish exposed to predation to all surviving PIT-tagged fish showed no significant difference between groups. Mean size of introduced PIT-tag fish was 59.9 mm (SD = 5.21) while mean size of survivors was 60.7 mm (SD = 5.28). A Kolmogorov-Smirnov test was used to compare the size of the PIT tagged survivors to the size of PIT-tagged fish initially stocked in predation tanks in each trial; the test showed no significant differences in their cumulative frequency distributions (P > 0.05). These results suggested there was no significant relationship between tagged fish size and vulnerability to predation.

Swimming Stamina

In both 1991 and 1992, the presence or absence of PIT tags in subyearling chinook salmon was significant in explaining the variability in swimming stamina as measured by U-critical swimming speed (ANOVA; P < 0.05). For 1991 results, an interaction variable (tagging by recovery period) was also significant in the ANOVA, indicating that swim performances of treatment and control fish were affected differently depending on recovery period. Swim chamber position, experimental trial, and fork length were not significant variables in the ANOVA (P > 0.05). For 1992 results, the interaction variable (tagging by

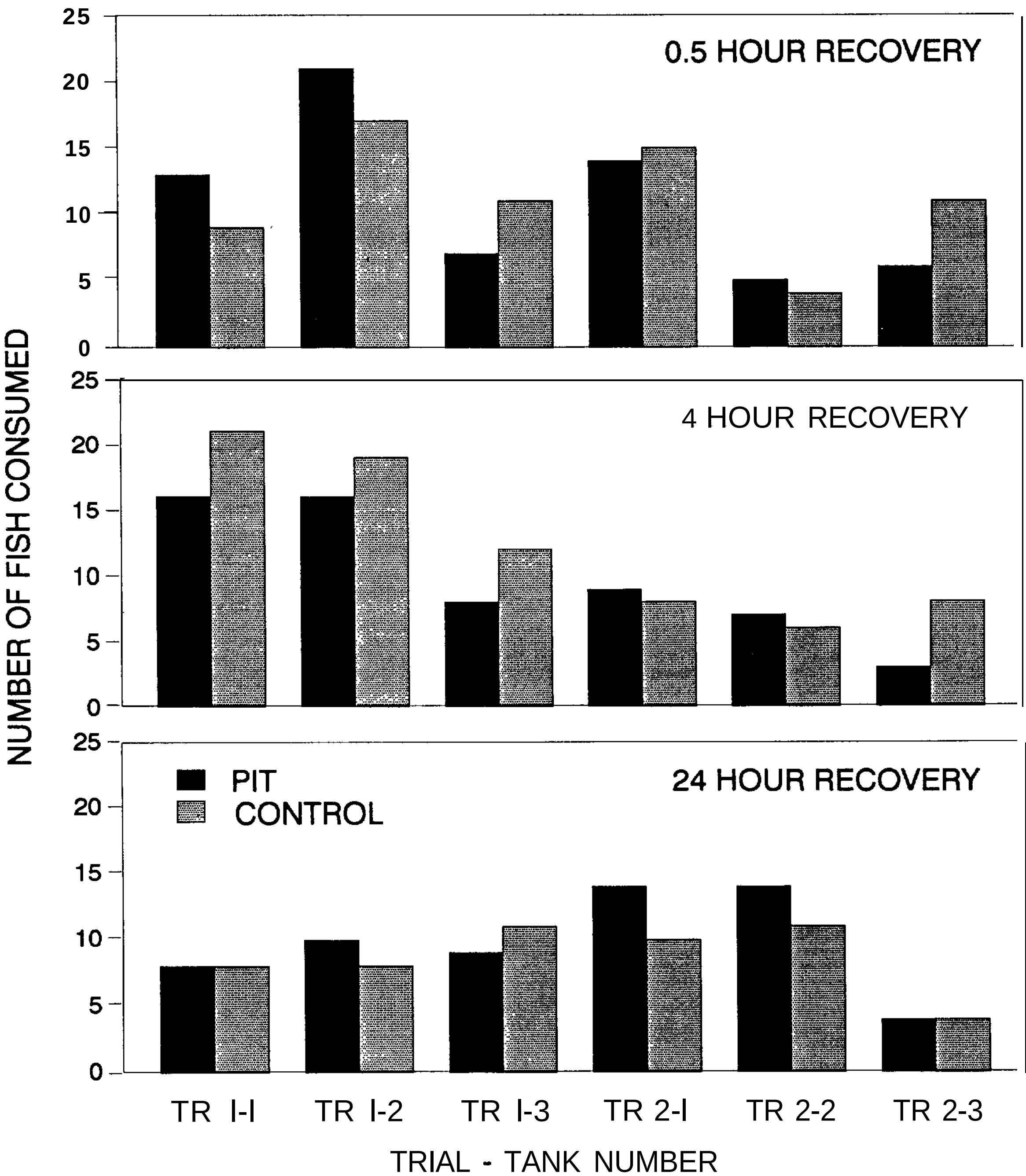

Figure 2.-Total number of juvenile chinook salmon eaten in 1992 predation vulnerability trials. Trials begun on 4 May and 11 May are shown separately as are individual tanks (1,2, and 3) in which tests were conducted. The three recovery periods, 0.5 h, 4 h, and 24 h, are included for comparison.

Table 3.-Results of predation risk experiments conducted in 1992 in which PIT-tagged juvenile fall chinook salmon allowed 0.5 hour recovery and controls were exposed to 24 hour predation risk by smallmouth bass.

Tag	Exp#-tank#	Number eaten	Expected# eaten	Chi-square	P-value
PIT	1-1	13	11.0	0.727	0.602
Control		9			
PIT	1-2	21	19.0	0.421	0.524
Control		17			
PIT	1-3	7	9.0	0.889	0.652
Control		11			
PIT	2-1	14	14.5	0.034	0.847
Control		15			
PIT	2-2	5	4.5	0.111	0.738
Control		4			
PIT	2-3	6	8.5	1.471	0.223
Control		11			
PIT	Pooled	66	66.5	0.008	0.928
Control		67			
Total				3.653	0.603

Table 4.—Results of predation risk experiments conducted in 1992 in which PIT tagged juvenile fall chinook salmon allowed 4 hour recovery and controls were exposed to 24 hour predation risk by smallmouth bass.

Tag	Exp#-tank#	Number eaten	Expected# eaten	Chi-square	P-value
PIT	1-1	16	18.5	0.676	0.583
Control		21			
PIT	1-2	16	17.5	0.257	0.618
Control		19			
PIT	1-3	8	10.0	0.800	0.625
Control		12			
PIT	2-1	9	8.5	0.059	0.802
Control		8			
PIT	2-2	7	6.5	0.077	0.778
Control		6			
PIT	2-3	3	5.5	2.273	0.128
Control		8			
PIT	Pooled	59	66.5	1.692	0.190
Control		74			
Total				4.141	0.531

Table S.-Results of predation risk experiments conducted in 1992 in which PIT tagged juvenile fall chinook salmon allowed 24 hour recovery and controls were exposed to 24 hour predation risk by smallmouth bass.

Tag	Exp#-tank#	Number eaten	Expected# eaten	Chi-square	P-value
PIT	l-l	8	8.0	0.000	1.000
Control		8			
PIT	l-2	10	9.0	0.222	0.643
Control		8			
PIT	l-3	9	10.0	0.200	0.659
Control		11			
PIT	2-l	14	12.0	0.667	0.580
Control		10			
PIT	2-2	14	12.5	0.360	0.556
Control		11			
PIT	2-3	4	4.0	0.000	1.000
Control		4			
PIT	Pooled	59	55.5	0.441	0.514
Control		52			
Total				1.449	0.918

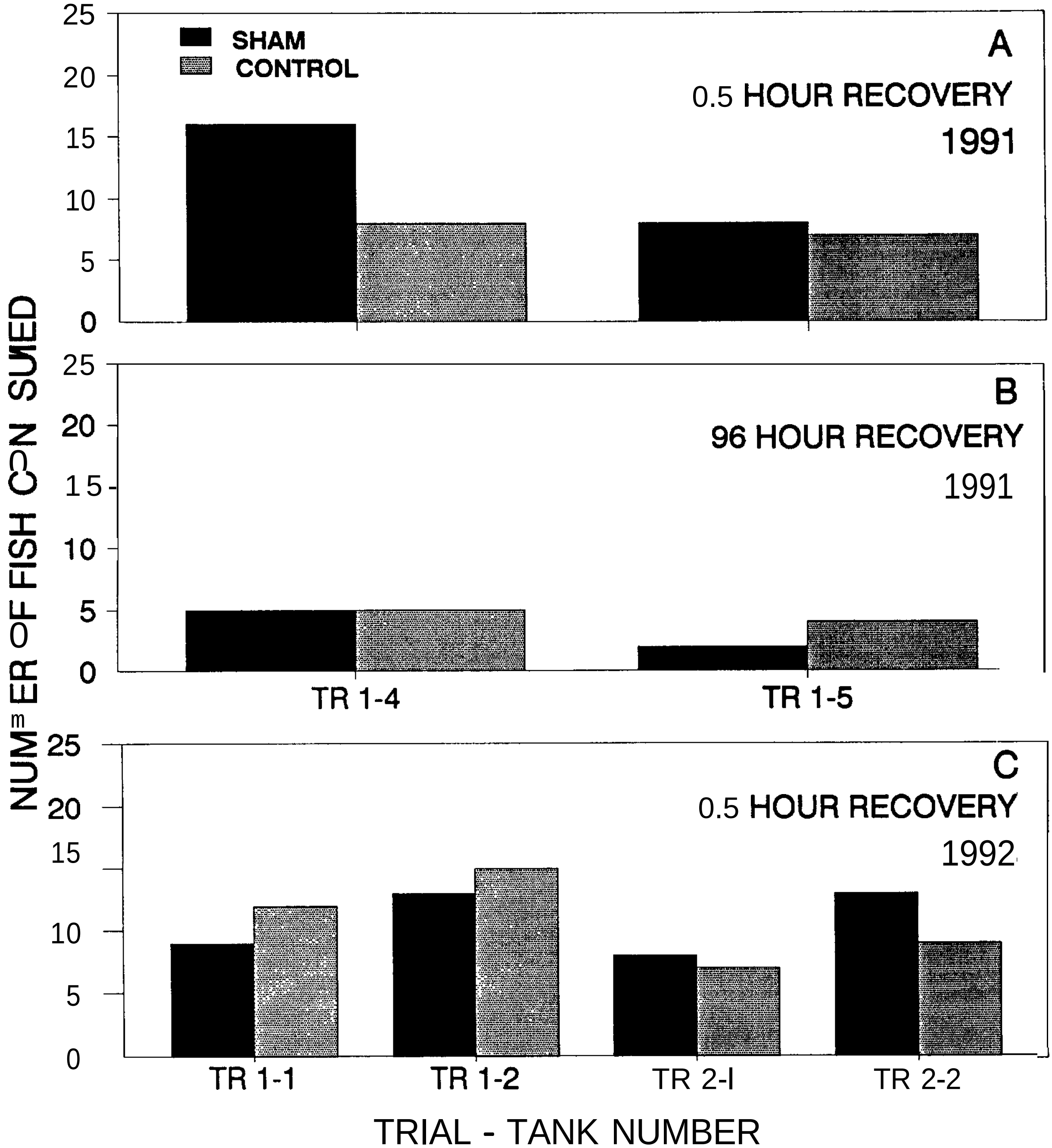

Figure 3.-Total number of juvenile chinook salmon eaten in predation vulnerability experiments in which treatment fish were sham tagged. Two 1991 recovery periods, 0.5 h (A) and 96 h (B) are shown for comparison. Graph C shows 1992 results of 0.5 h recovery trials.

recovery period) was not significant indicating they recovered in a similar manner.

In 1991, fish tested after a 0.5 h recovery period had significantly lower swimming stamina than those allowed 4 h or more recovery time when compared using Tukey's test of means (Table 6 and 7). The 1991 results show the U-criticals of treatment fish were lower than controls when allowed 0.5 h recovery, but comparable with controls when tagged fish were allowed four or more hours recovery (Figure 4). In 1992 swimming stamina tests, treatment fish had significantly lower mean swimming stamina than control fish according to Tukey's comparison of means (Table 8). All tag groups performed more poorly than controls during 1992 tests (Figure 5).

Tag Retention and Delayed Mortality

Tag retention for all groups of PIT-tagged fish was greater than 97% in 1991 tests (Table 9). In the first trial of the 1991 experiment, begun on 10 May, overall tag retention was 97%, while in the second trial, begun May 17 tag, retention improved to over 99%. Mortality for all groups of treatment fish, including those held for 96 h predation trials, was 20% compared to no mortality for control groups. In those tanks where treatment fish were held for tag retention and mortality tests, mortality ranged from 7% to 27% of the fish stocked in each tank compared to no mortalities in the control groups (Table 10).

Longterm Growth

During the 1992 longterm growth experiments, only the middle size group showed a significant difference in mean length at any time (Table 11). While lengths and weights were taken on 28 July the data was not useful because control fish were no longer distinguishable from treatment fish that might have lost their tags. In fact counts showed over 100 control fish in both the middle, and large size groups on July 28. Treatment fish that had lost tags were being identified as control fish because their tag insertion scars were no longer visible. Through 25 June mortality of control fish was 6% while treatment fish mortality was 7% (20 control and 21 treatment mortalities were counted that date).

Discussion

The effects of tagging on subyearling fall chinook salmon behavior were substantial, but appeared to be short term. In 1991, predation on tagged fish by smallmouth bass in the predation vulnerability tests indicated that 96 h recovery provided considerable benefits over just 0.5 h recovery times.

Table 6.—1991 swimming stamina comparison tests between PIT tagged and control subyearling chinook salmon. Mean $U_{critical}$[a], lengths and standard deviations are listed for each group of six PIT tagged and six control fish swum simultaneously in a divided swim chamber.

Recovery Period	PIT Tag Mean FL (std)	PIT Tag Mean Ucrit. (std)	Control Mean FL (std)	Control Mean Ucrit. (std)
Replicate 1				
0.5 hours	58.0 (1.00)	3.09 (1.87)	57.5 (1.26)	5.99 (0.82)
0.5 hours	57.7 (1.11)	3.76 (2.38)	57.8 (1.34)	6.69 (1.13)
24 hours	57.2 (1.34)	8.60 (2.26)	56.3 (2.69)	7.87 (2.09)
24 hours	56.3 (2.05)	6.60 (1.73)	57.8 (2.67)	7.49 (0.92)
96 hours	58.0 (1.41)	7.70 (1.79)	56.3 (1.80)	7.92 (1.05)
96 hours	59.5 (0.50)	8.26 (1.37)	56.2 (1.68)	8.10 (1.09)
Replicate 2				
0.5 hours	58.2 (1.77)	6.47 (2.00)	60.2 (1.57)	7.16 (1.02)
0.5 hours	58.5 (1.89)	5.00 (2.89)	57.0 (1.41)	7.36 (1.05)
4 hours	59.7 (1.60)	7.07 (0.88)	54.7 (2.13)	7.11 (0.64)
4 hours	57.5 (2.99)	7.16 (2.54)	59.8 (2.03)	7.41 (1.42)
48 hours	55.7 (1.60)	6.88 (1.45)	56.0 (4.47)	6.60 (1.43)
48 hours	56.8 (3.44)	7.14 (1.70)	57.3 (1.49)	7.46 (0.83)
96 hours	55.5 (0.96)	7.50 (0.54)	53.0 (3.42)	6.89 (0.87)
96 hours	58.3 (1.80)	7.60 (0.35)	55.8 (3.67)	7.53. (0.57)

[a] $U_{critical}$ were determined by swimming fish in a flume with a beginning velocity of 1.5 body lengths per second (1 BdL=60mm) and increasing the velocity 0.5 body lengths every 15 minutes. $U_{critical}$ express the highest 15 minute velocity increment (BdL/sec) the fish swam at plus the proportion of the last increment during which the fish was exhausted.

Table 7.—1992 Swimming stamina comparison tests between PIT tagged and control subyearling chinook salmon. Mean $U_{critical}$[a], lengths and standard deviations are listed for each group of six PIT tagged and six control fish swum simultaneously in a divided swim chamber.

Recovery Period	PIT Tag Mean FL (std)		PIT Tag Mean Ucrit. (std)		Control Mean FL (std)		Control Mean Ucrit. (std)	
Replicate 1								
0.5 hours	64.2	(1.95)	5.70	(0.37)	59.8	(2.19)	5.58	(0.80)
0.5 hours	63.8	(3.34)	5.16	(0.61)	63.8	(2.79)	5.44	(0.21)
4 hours	61.3	(2.49)	5.53	(0.35)	62.2	(1.86)	5.72	(0.36)
4 hours	62.7	(2.56)	4.89	(1.17)	61.7	(3.25)	5.36	(0.32)
24 hours	62.7	(3.40)	5.59	(0.76)	63.3	(3.25)	5.78	(0.71)
24 hours	62.0	(3.31)	4.83	(1.04)	62.2	(4.63)	5.46	(0.49)
Replicate 2								
0.5 hours	66.3	(3.49)	5.13	(1.09)	66.0	(1.91)	5.33	(0.51)
0.5 hours	65.5	(2.14)	5.23	(0.42)	67.3	(3.40)	5.79	(0.58)
4 hours	63.2	(2.11)	5.13	(0.75)	65.5	(4.31)	5.52	(0.40)
4 hours	65.7	(1.97)	4.26	(1.04)	63.7	(3.20)	3.19	(2.36)
24 hours	63.8	(2.11)	5.30	(1.05)	67.7	(3.73)	6.24	(0.80)
24 hours	64.7	(4.82)	5.26	(1.33)	64.3	(1.60)	5.24	(1.10)

[a] $U_{critical}$ were determined by swimming fish in a flume with a beginning velocity of 1.5 body lengths per second (1 BdL=60mm) and increasing the velocity 0.5 body lengths every 15 minutes. $U_{critical}$ express the highest 15 minute velocity increment (BdL/sec) the fish swam at plus the proportion of the last increment during which the fish was exhausted.

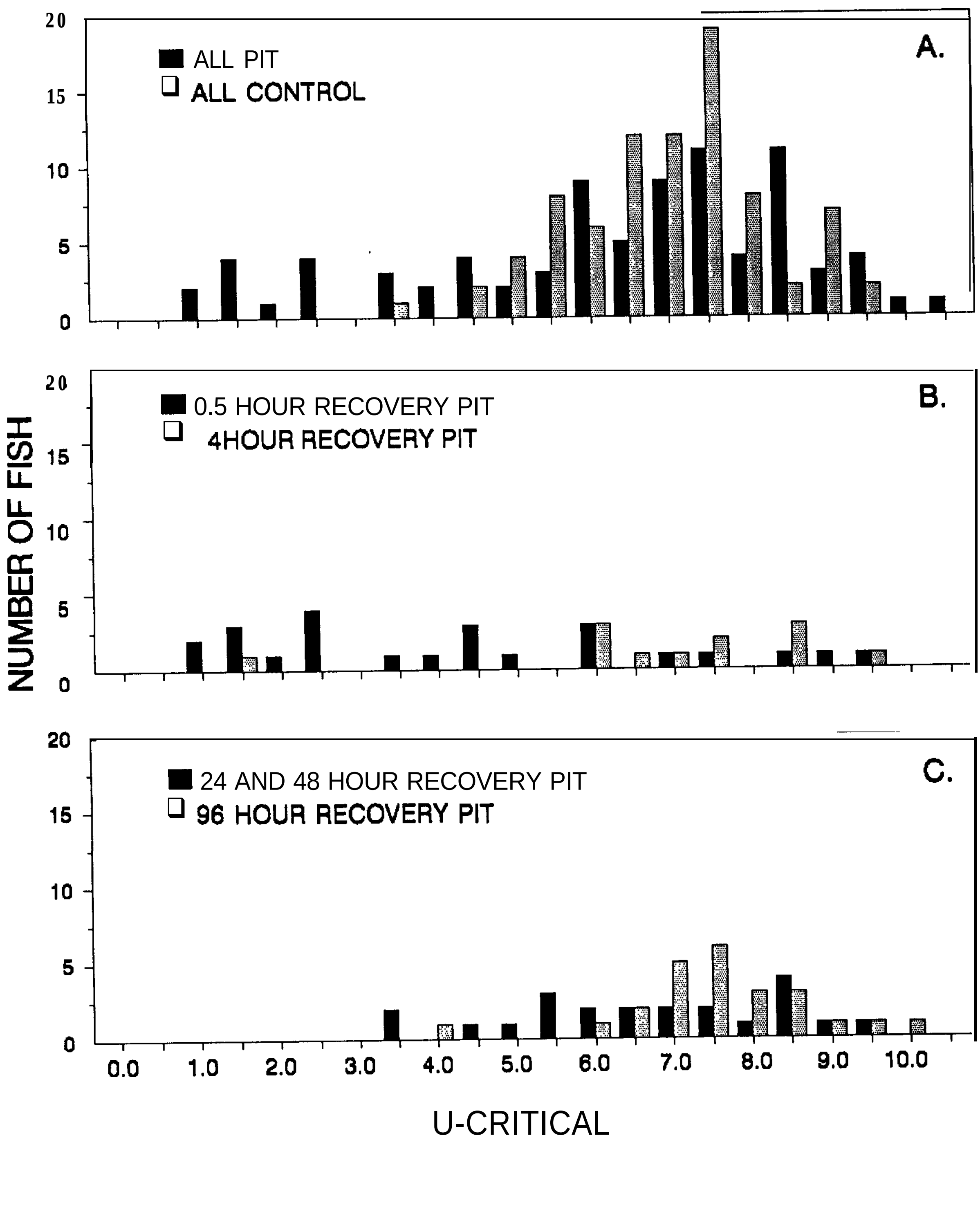

Figure 4 .-Frequency histograms of U-critical values for all fish tested. A. All PIT-tagged and all control fish. B. PIT-tagged fish with 0.5 h and 4 h recovery periods. C. PIT-tagged fish with 24 h, 48 h, and 96 h recovery periods.

Table 8.-Tukey's studentized range (HSD) test of mean Ucriticals for each recovery period for all fish (PIT tag and controls) . Alpha= 0.05 Confidence= 0.95 df= 158 MSE= 2.890148. Critical Value of Studentized Range= 3.903. Comparisons significant at the 0.05 level are indicated by '***'.

RECOV Comparison	Simultaneous Lower Confidence Limit	Difference Between Means	Simultaneous Upper Confidence Limit	
96 - 24	-1.127	0.045	1.218	
96 - 4	-0.736	0.437	1.610	
96 - 48	-0.506	0.666	1.839	
96 - 0.5	1.006	1.964	2.921	***
24 - 96	-1.218	-0.045	1.127	
24 - 4	-0.963	0.391	1.746	
24 - 48	-0.733	0.621	1.975	
24 - 0.5	0.746	1.918	3.091	***
4 - 96	-1.610	-0.437	0.736	
4 - 24	-1.746	-0.391	0.963	
4 - 48	-1.125	0.230	1.584	
4 - 0.5	0.354	1.527	2.700	***
48 - 96	-1.839	-0.666	0.506	
48 - 24	-1.975	-0.621	0.733	
48 - 4	-1.584	-0.230	1.125	
48 - 0.5	0.125	1.297	2.470	***
0.5 - 96	-2.921	-1.964	-1.006	***
0.5 - 24	-3.091	-1.918	-0.746	***
0.5 - 4	-2.700	-1.527	-0.354	***
0.5 - 48	-2.470	-1.297	-0.125	***

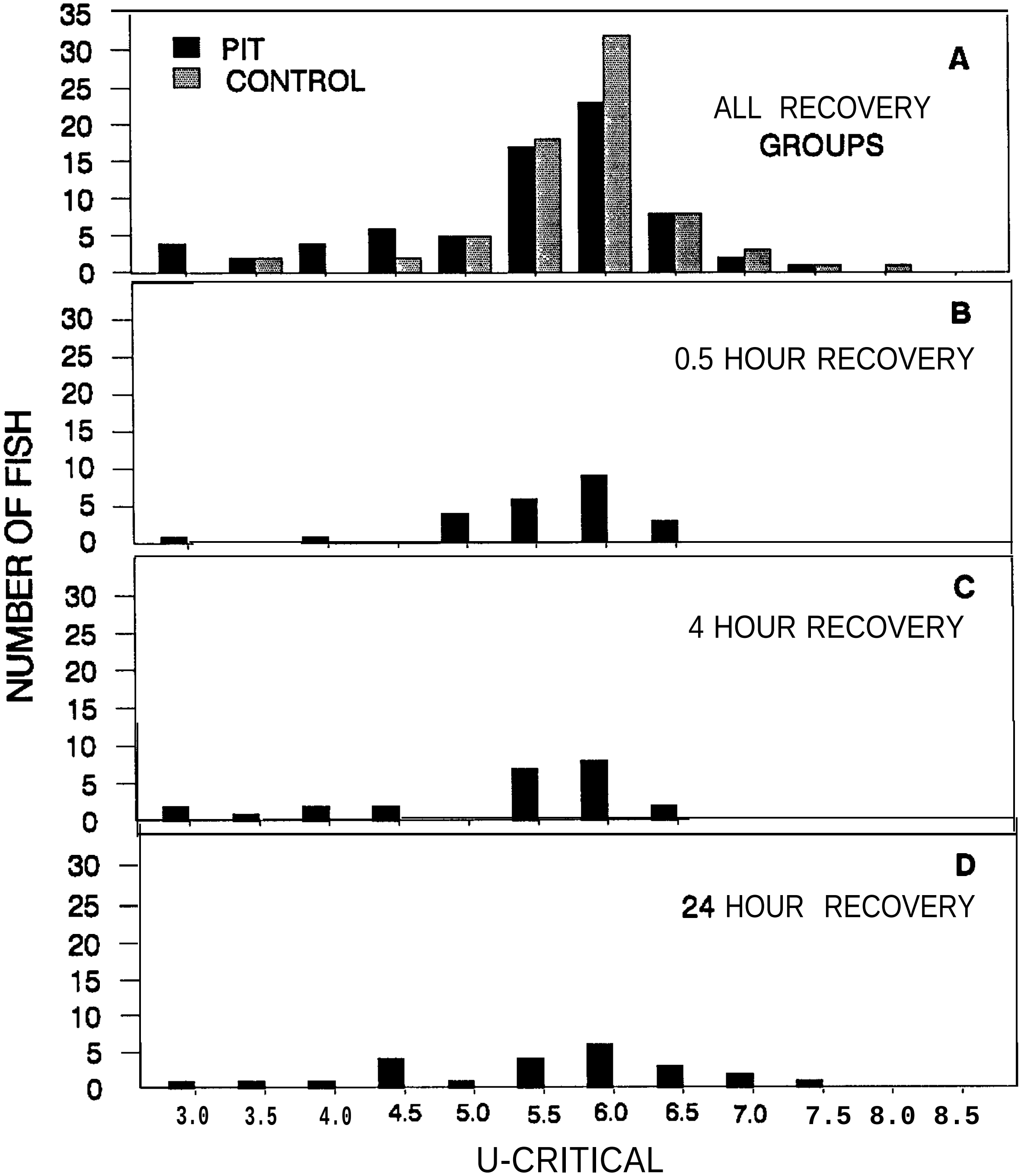

Figure 5.-Frequency histograms of U-critical values for all fish tested. A. All PIT-tagged and all control fish. B. PIT-tagged fish with 0.5 h recovery period. C. PIT-tagged fish eith 4 h recovery period. D. PIT-tagged fish with 24 h recovery period.

Table 9.-Delayed mortality of subyearling fall chinook salmon PIT tagged (on 10 May 1991--experiment one and 17 May 1991--experiment two) and held in tanks compared to mortality in subyearlings neither tagged nor anesthetized (control). Forty fish were held in each tank.

	Mortalities and percent mortality			
Hours after tagging	PIT tag	control	PIT tag	control
24				
Rep. 1	10 (25%)	0 (0%)	7 (17%)	0 (0%)
Rep. 2	11 (27%)	0 (0%)	3 (7%)	0 (0%)
48				
Rep. 1	1 (27%)	0	0	0
Rep. 2	0	0	0	0
72				
Rep. 1	0	0	0	0
Rep. 2	0	0	0	0
96				
Rep. 1	0	0	0	0
Rep. 2	0	0	0	0
Cumulative Mortality				
Rep. 1	11 (27%)	0 (0%)	7 (17%)	0 (0%)
Rep. 2	11 (27%)	0 (0%)	3 (7%)	0 (0%)
Total Mortality	22 (27%)	0 (0%)	10 (12%)	0 (0%)

Table 10.—Percent of PIT tags retained up to 96 hours by subyearling chinook salmon tagged on 10 May 1991.

Group	Number of fish PIT tagged	Tag retention	
		Number	Percent
Delayed Mortality			
Rep. 1	81	77	95
Rep. 2	81	80	99
Swim Test			
Rep. 1	59	57	97
Rep. 2	64	64	100
Predation by recovery period (0.5 hour)			
Rep. 1	53	51	96
Rep. 2	64	64	100
(96 hour)			
Rep. 1	60	60	100
Rep. 2	80	79	99
514			
Rep. 1	10	10	100
Rep. 2	15	15	100
Cumulative			
Rep. 1	263	255	97
Rep. 2	304	302	99

Table Il.-Results of longterm growth tests in which treatment and control fish were held in tanks and periodically weighed and measured.

Tank	Date	Tag Group	Mean FL	Pooled STD	*t*	t-Table
A	5/13	CONTROL	55.6	2.42	1.92	1.97
	5/13	TREATMENT	56.2			
	6/04	CONTROL	62.0	3.42	1.78	1.98
	6/04	TREATMENT	60.8			
	6/25	CONTROL	72.8	4.62	0.92	0.98
	6/25	TREATMENT	73.4			
	7/28	CONTROL	83.9	---	---	---
	7/28	TREATMENT	84.4			
B	5/13	CONTROL	64.7	2.59	1.02	1.97
	5/13	TREATMENT	64.4			
	6/04	CONTROL	69.6	3.27	2.41*	1.98
	6/04	TREATMENT	68.0			
	6/25	CONTROL	83.4	4.62	1.49	1.98
	6/25	TREATMENT	82.0			
	7/28	CONTROL	95.7	---	---	---
	7/28	TREATMENT	93.5			
C	5/13	CONTROL	71.5	1.60	0.0	1.97
	5/13	TREATMENT	71.5			
	6/04	CONTROL	78.7	3.04	0.69	1.98
	6/04	TREATMENT	79.2			
	6/25	CONTROL	90.2	4.59	1.04	1.98
	6/25	TREATMENT	91.1			
	7/28	CONTROL	101.2	---	---	---
	7/28	TREATMENT	102.4			

Those means marked with an asterisk (*) are those that are significantly different according to the Student's *t* (alpha = 0.05).
t-tests were not reported for data recorded on 7/28 because treatment fish that had lost tags could no longer be distinguished from control fish due to healing of tag insertion scars.

Inasmuch as mortality was relatively high among tagged groups during the first 24 h after **tagging** those individuals selected by smallmouth bass may have been in similar condition to individuals that died in the delayed mortality tests. By contrast, in 1992, predation vulnerability of treatment fish was not different compared to controls in 0.5 h, 4 h, and 24 h groups. This difference in results was likely related to improved tagging techniques which greatly reduced mortality in tagged fish. The size of the tagged fish might also have contributed this difference because in 1491, fish as small as 48 mm were tagged while in 1992, no fish were tagged under 60 mm.

During 1991 trials, PIT tagging significantly lowered the swim performance of fish allowed only 0.5 h to recover from tagging. Treatment fish allowed four or more hours to recover performed as well as control fish in swim performance tests. In 1992 all treatment-recovery groups had lower swim stamina than controls.

PIT tagging caused high mortality in 1991 experiments. Prentice et al. (1986) found mortality rate (4%) did not increase significantly in fish as small as 64 mm average fork length. In 1992 longterm growth trials, the mortality rate attributable to PIT tagging was less than 1 percent. The high mortality rate we observed in 1991 trials, 20% overall, might have been due to the relatively small size of the fish tagged, administration of the anesthetic, tagging technique, and the inexperience with tagging small fish.

A significant change in tagging technique, in 1992, was the use of a buffered anesthetic. Other investigators have found that buffered anesthetic can result in reduced mortality when using soft water (Wedemeyer 1970; Soivio et al. 1977; Sylvester and Holland 1982). The combination of anesthetizing too many fish at one time and the relatively slow rate of PIT tagging with a syringe might also have caused high mortality in earlier experiments. Furthermore, in the field where the average catch rate was 2.1 fish per seine haul, the small number of fish made the anesthetizing and handling relatively quick despite working from a boat.

Initially we assumed that our inexperience with tagging relatively small fish may have attributed to the high post tagging mortality. However, training tests with an inexperienced person contradict that assumption since a 4% mortality rate was observed. The tagging technique is very important for relatively small fish. Prentice et al. (1990b) indicated that once the needle passes through the body wall musculaturer, the needle angle is changed and then inserted farther until its point is posterior to the pyloric caecae near the pelvic girdle. However, we found that after the needle passes through the body wall, it can be backed out and the tag inserted into the body cavity resulting in less internal intrusion and higher tag retention.

The validity of migration timing data of the Snake River fall chinook salmon relies on whether or not tagged fish behave in a manner similar to the untagged fish. This question can only be partially answered by laboratory experiments. Knowing the effects of tagging on swim performance and predation vulnerability is not equivalent to knowing the effects of tagging on such specialized beha'vior as migration timing. However, these tests do indicate that some behavior (such as predator avoidance) may not be affected if fish are allowed an adequate recovery period.

Conclusions

1. In 1992 experiments, delayed mortality of PIT-tagged fish ranged from 7% to 27% and occurred primarily in the first 24 h after tagging. During long-term growth experiments conducted in 1992, with a rearing period of 44 d, mortality rate attributable to PIT tagging was 1%.

2. Factors that we believe contributed to the lower mortality of subyearling chinook salmon in 1992 versus 1991 were improved tag insertion technique, the larger size of experimental fish in 1992, and, most importantly, the application of anesthetic. Use of buffered anesthetic and shorter total exposure times to anesthetic may be critical factors in reducing mortality.

3. The reduction of predation vulnerability of 0.5 h treatment recovery groups from 1991 to 1992 may have been related to reduced mortality rate and therefore related to those factors listed in conclusion 2.

4. Predation of PIT-tagged fish was not size selective based on the comparison of the size PIT-tagged fish stocked into predation tanks versus the size of fish surviving the tests.

5. A comparison of U-critical swimming speed of PIT-tagged and control fish allowed to recover for time periods ranging from 0.5 h to 96 h indicated that effects from tagging on swimming performance could be as long as 24 h. Furthermore, stresses related to PIT tagging appear to affect swim stamina differently than mortality rate and predation vulnerability.

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CHAPTER FIVE

Rearing and Emigration of Naturally Produced Snake River Fall Chinook Salmon Juveniles

by

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Introduction

Minimal data are available on the rearing and emigration of juvenile Snake River fall chinook salmon *Oncorhynchus tshawytscha*. When Snake River fall chinook salmon were listed as a threatened species under the Endangered Species Act (ESA; United States Fish and Wildlife Service 1988) in 1992, much of the contemporary information on these subyearling emigrants was based on our 1991 research (Connor et al. 1993). The purpose of our study is to increase the information on naturally produced Snake River fall chinook salmon juveniles for ESA recovery efforts. Our objectives in 1992 were: 1) describing the early life history and emigration timing of naturally produced Snake River fall chinook salmon, and 2) estimating the influence of water flow, water temperature, and juvenile fall chinook salmon size on emigration rate.

Study Area

The study area included the Snake River from Hells Canyon Dam to Lower Granite Dam (Figure 1). In 1992, we gathered data by seining and tagging juvenile chinook salmon in **a** reach bounded by Two Corral Creek at river kilometer (RK) 355 and Lower Granite Dam (RK 173); within this reach we seined 19 different systematic sites. Mean daily Snake River discharge at the United States 'Geological Survey gage at Anatone, Washington (RK 270) ranged from about 15,300 to 47,200 cubic ft/s (CFS) during sampling (Figure 2). Mean daily water temperature collected at Billy Creek (RK 265) ranged from about 9.5 to 18.4°C during sampling (Figure 2).

Methods

Data Collection

Systematic samples.-Nineteen sites (Table 1) were beach seined once each week from 1 April until 14 May, 1992. Each site was normally seined three times in an upriver direction; each consecutive set started where the previous one ended. From 19 May to 11 June we seined only the lower 15 sites between RK 226 and RK 290. The beach seine we used from 1 April to 6 May had 0.32 cm mesh and measured 21.3 m x 1.2 m. This seine had a 1.7 m^3 bag and a weighted multistranded mudline. On 12 May, we switched to a larger seine. The larger seine had 0.48 cm mesh and was 30.5 m x 1.8 m with a 3.9 m^3 bag. Each end of the seine was fitted with a bottom weighted brail equal in length to net depth and 15.2 m lead ropes. The seine was set parallel to shore

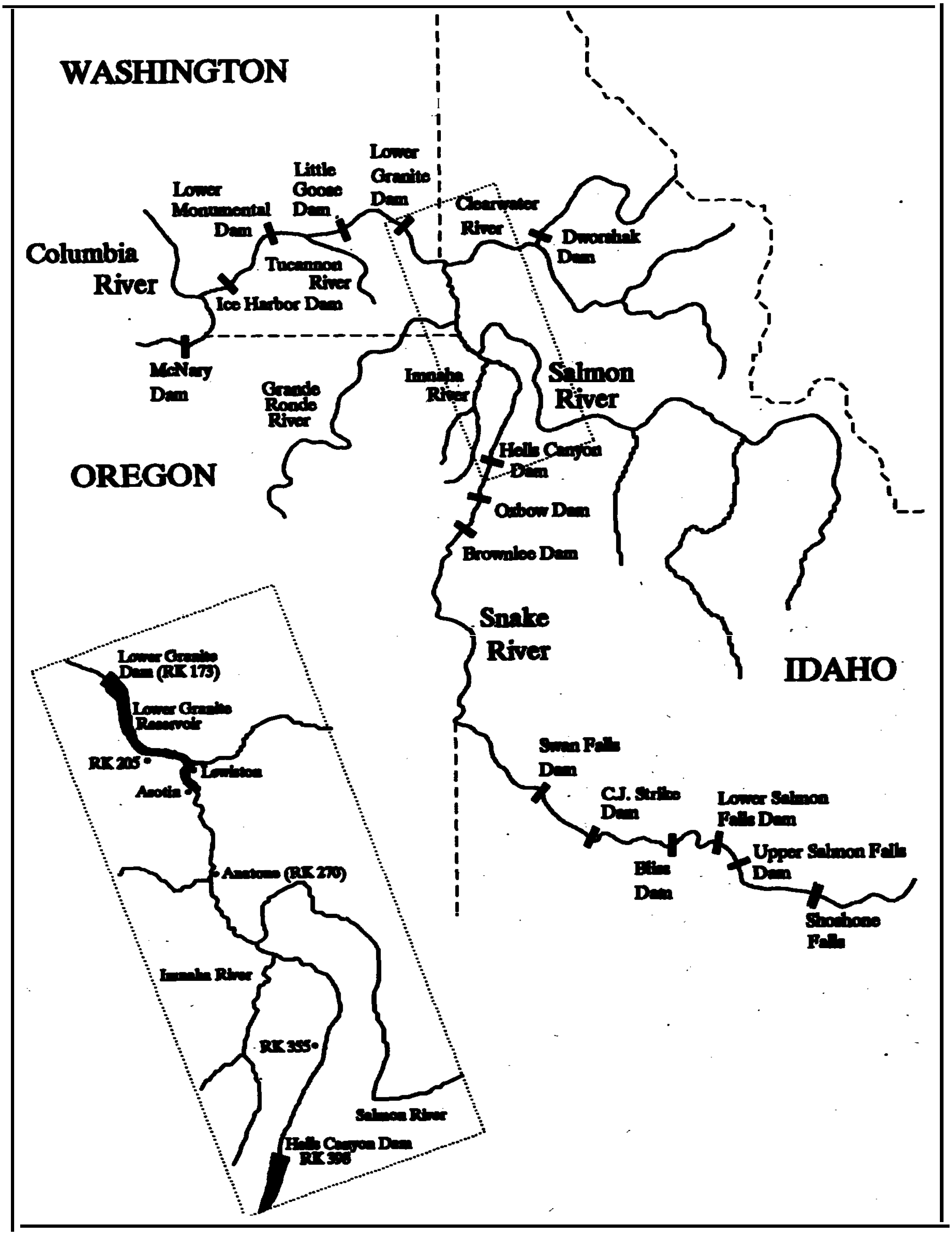

Figure 1.- Map of the Snake River drainage with an insert to show the 1992 seining area boundaries of RK 205 and RK 355.

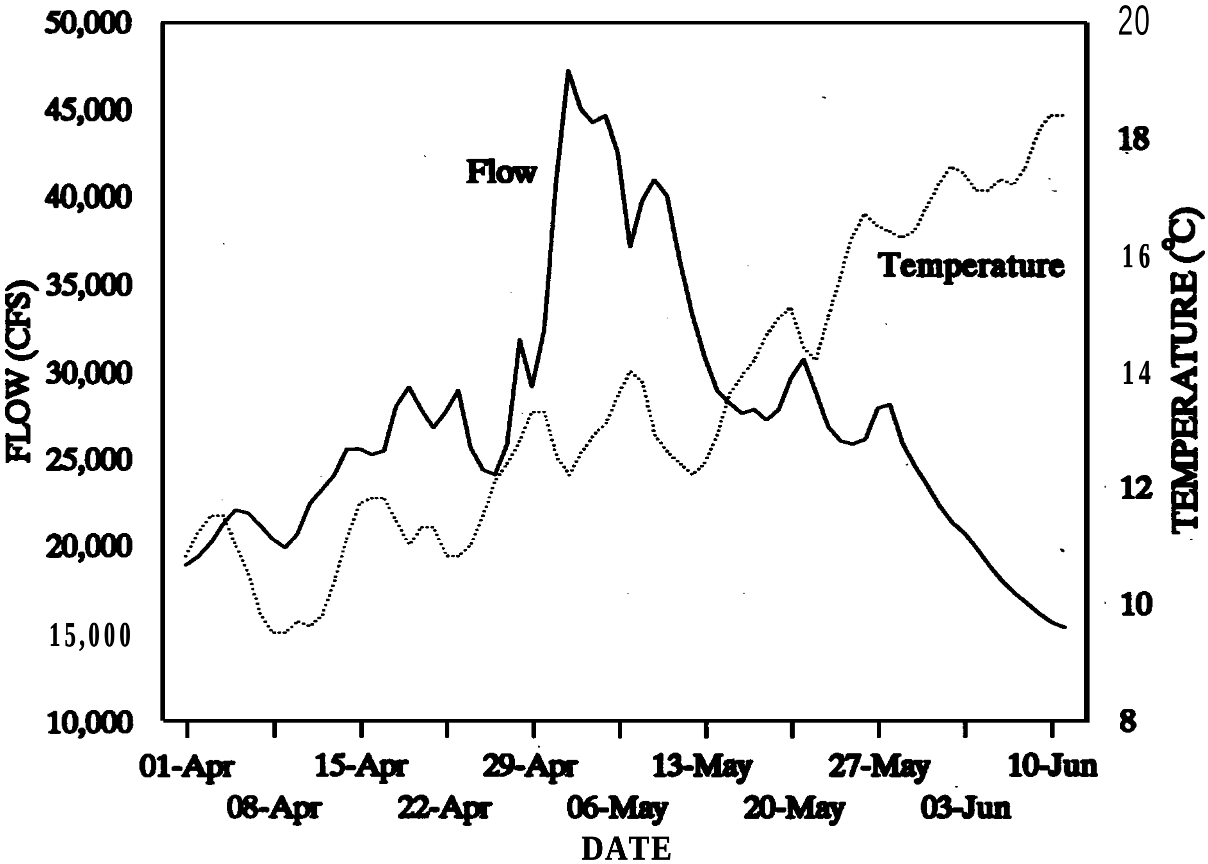

Figure 2.–Mean daily flows (RK 270) and temperature (RK 265) in the Snake River during the 1992 sampling period.

from the stern platform of a 6.7 m jet boat. The net was then hauled straight into shore by both lead ropes. The smaller net sampled approximately 324 m^2 of river to a depth of 1.2 m, while the larger net sampled 465 m^2 to a depth of 1.8 m.

Table l.-Sites seined for systematic fall chinook salmon juvenile sampling in the Snake River in 1992.

River Kilometer	Side of River
226	West
229	East
232	East
242	East
242	West
248	West
251A	East
251B	East
254	West
262	East
272	East
274	East
280	West
282	East
290	East
322	East
328	West
346	West
355	West

Grab samples.-Seine hauls made at locations other than, or adjacent to, systematic sampling sites were classified as grab samples. We collected fishes from 23 grab sites. Grab sites were selected based upon habitat features that were similar to our systematic seining sites. These sites are generalized by low velocity and sloping shore with minimal obstructions for landing a beach seine. Grab sites were sampled after systematic sites were finished for the day or on days when no systematic sampling was scheduled.

Anesthetic. -Once seined, chinook salmon were transferred to a 94.6 L oxygenated live-well supplied with water at river temperature, 100 g of NaCl, and 12.5 mL of polyaqua. All chinook salmon were anesthetized in a dilute tricaine methanesulfonate (MS-222) solution of 2-5 mL of concentrated MS-222 to 18.9 L of water, which was buffered with 0.5 gm of $NaHCO_3$. The concentrate was prepared by mixing 100 gm of powdered MS-222 in a 100 mL of water. The MS-222 concentrate was kept refrigerated and was stored in a dark plastic bottle. Chinook salmon were anesthetized in groups of 6-10 fish.

In-season race identification.-We calculated a size limit to separate the smaller subyearling chinook salmon juveniles "in-season" from larger yearling chinook salmon. The size limit was calculated based on water temperature, projected fry emergence dates, and projected growth rate. Fork length (FL) of all anesthetized chinook salmon juveniles that obviously fit within the size limit were measured to the nearest millimeter. If the fish were out side of the size limit we measured FL of about 30 randomly sampled chinook salmon.

Water temperature data for the size limit calculation were collected at Pittsburg Landing (RK 347) and Billy Creek (RK 265) These temperature data were used to project fry emergence, documented to occur at 962 Celsius temperature units (CTUs; Arnsberg et al. 1992) after spawning. For the size limit calculation, emergent fry were estimated to be 38 mm FL (Arnsberg et al. 1992), and estimated to have a growth rate of 1.4 mm/d (Connor et al. 1993). Emergence timing had to be projected separately for chinook salmon juveniles collected above and below the Salmon River confluence because of differences in water temperature. We calculated the upper fall chinook salmon size limit in Table 2 using water temperatures from RK 265. A maximum upper limit of 110 mm was used since fall chinook salmon larger than this size were rare in 1991 (Connor et al. 1993). The lower fall chinook salmon size limit in Table 2 was calculated using a 60 mm minimum tagging size and water temperatures from RK 347.

Table 2.-Upper and lower size limits calculated for in-season race identification of chinook salmon seined in the Snake River, 1992.

Limit	Estimated fall chinook salmon size by date								
	13-Apr	20-Apr	27-Apr	4-May	ll-May	18-May	25-May	1-Jun	8-Jun
Upper	64	68	72	76	90	95	103	110	110
Lower	60	60	60	60	60	60	60	60	60

PIT tagging.-Chinook salmon which fit within the size limits of Table 2 or had the sharper body features and smaller eyes we noted in fall chinook salmon during 1991 were Passive Integrated Transponder (PIT) tagged (Prentice et al 1990a). The minimum size limit for PIT tagging chinook salmon was 60 mm FL based on laboratory data by colleagues (McCann et al. 1993). From 14 April to 14 May, 1992 we used a 50% solution of iodine for a tag disinfectant. This disinfection method was based on a discussion with fish health experts at the American Fisheries Societies Smolt Survival Workshop '(February, 1992). Notably, the tags were not rinsed prior to injecting them into the chinook salmon. The excess iodine from the tag and the needle (about 0.05 g) passively dispersed on the surface and edges of the insertion wound. Laboratory work to isolate the effects of the above iodine treatment were done on 15 May, 1992. Twenty-five hatchery fall chinook salmon juveniles ranging in size from 58-74 mm FL were injected with 0.05 g of a 50% iodine solution and 33 hatchery fall chinook salmon juveniles ranging in size from 62-72 mm FL served as controls. Mortality of the treatment and control groups was monitored for 96 h.

From 19 May to 10 June 1992, we used 70% ethyl alcohol to disinfect the tags. The disinfected tags were blotted dry prior to insertion into the fish. Chinook salmon juveniles were immobilized by placing them in a cool, wet, notched foam pad. Tags were manually implanted with a 12 gauge needle affixed to a syringe.

Recovery.-After tagging, we transferred the fish to an oxygenated 18.9 L recovery bucket filled with saline water (20 gm NaCl) and 12.5 mL of polyaqua. The salmon were held in the recovery bucket for 15 min prior to a 24-h holding period in a 0.02 m^3 minnow trap that was secured to the bottom of the river by weights. This 24-h holding procedure was implemented from 14 April to 13 May. After 13 May we released salmon immediately after the 15 min recovery period.

PIT-tag data.-The data collected from the PIT-tagged chinook salmon juveniles were recorded in computer files (PIT Tag Work Group 1991). These tagging files were uploaded to the PIT Tag Information System (PITAGIS). Emigrating chinook salmon juveniles that bypass Lower Granite Dam turbines via the submersible travelling screen are monitored for PIT tags (Prentice et al. 1990b). Both PIT-tagging and PIT-tag detection data are available to interested parties through PITAGIS.

Electrophoresis.-A subsample of the PIT-tagged chinook salmon detected at Lower Granite Dam are diverted by a hydraulic slide gate. Diverted chinook salmon are scanned for tag codes and measured by Smolt Monitoring Program (SMP) personnel. When our tag codes were detected in chinook salmon a scale sample was taken for aging (Jerald 1983) and the fish was labeled and frozen. The Washington Department of Fisheries (WDF) validated the race of the frozen chinook salmon using tissue extracts and horizontal starch-gel electrophoresis (Abbersold et al. 1987).

Data Analysis

Post-season race separation.-The first step in our analysis was a description of the number and size of all the juvenile chinook salmon we beach seined. Then we used a simple process to separate out spring/summer chinook salmon data from fall chinook salmon data. We based our "post-season" separation of fall and spring/summer chinook salmon on data collected from our PIT-tagged, electrophoretically validated, fall chinook salmon juveniles diverted at Lower Granite Dam. The FL of the two known spring/summer chinook salmon were averaged. A line was then regressed through the FL of two spring/summer chinook salmon and the average FL calculated above. All fish smaller than this regressed upper size were separated as fall chinook salmon.

Emigration rate.-We calculated emigration rate for each PIT-tagged fall chinook salmon by dividing the distance between the release site and Lower Granite Dam by the time the fish was at large before being detected at the dam. Multiple General Linear Hypothesis testing (MGLH; SYSTAT 1990) was used to test for relations between and among fall chinook salmon emigration rate and, (a) Snake River average discharge at Lower Granite Dam when the fish was at large (emigration flow), (b) the Snake River average water temperature when the fish was at large (emigration temperature), (c) Snake River water temperature when the fish was released (release temperature), and (d) the FL of the PIT-tagged fall chinook salmon when it was released (release length; Appendix 5).

Results

Overview of Seining and Tagging

We beach seined 3,156 chinook salmon juveniles between 1 April and 10 June, 1992 at 19 systematic and 23 grab sites (Figure 3). The 2,710 chinook salmon we measured ranged from 34 to 210 mm FL (Figure 4). We PIT tagged 1,100 (total before post-season race separation by FL) of the 3,156 chinook salmon between 14 April and 10 June, 1992 (Figure 5). We only released 1,051 of the 1,100 tagged chinook salmon as a result of post-tagging mortality.

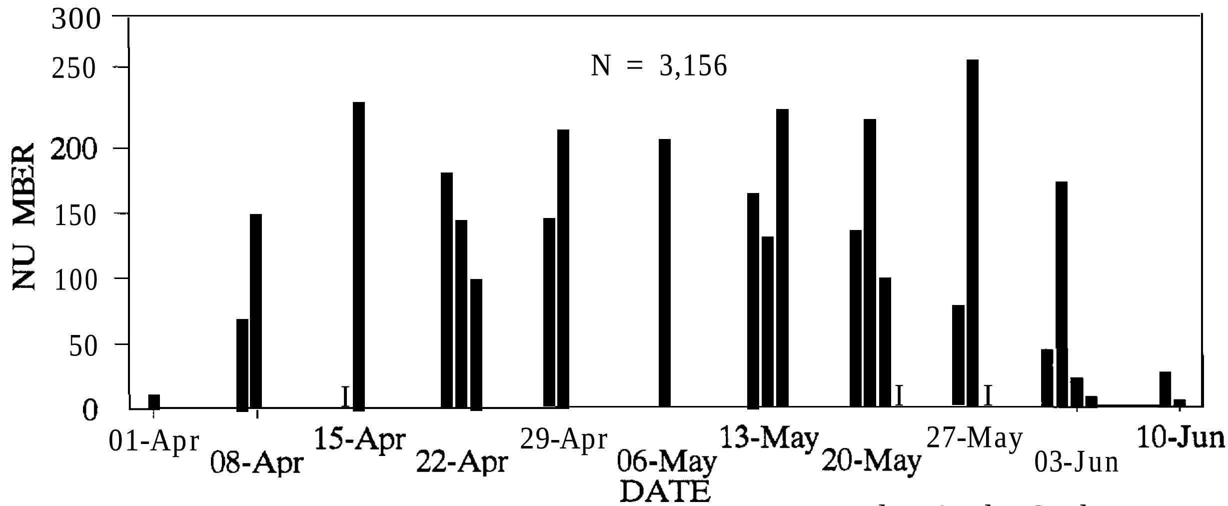

Figure 3.–Number of chinook salmon ‘uveniles seined by date in the Snake River between RK 205 and RK 355, 1 April to 10 June, 1992.

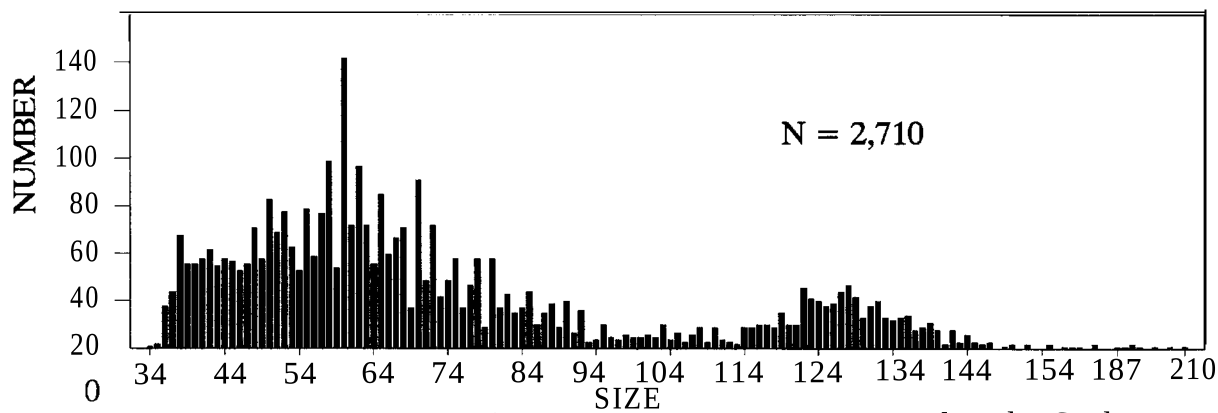

Figure 4.–Length frequency of chinook salmon (mm) Juveniles seined in the Snake River between RK 205 and RK 355, 1 April to 10 June, 1992.

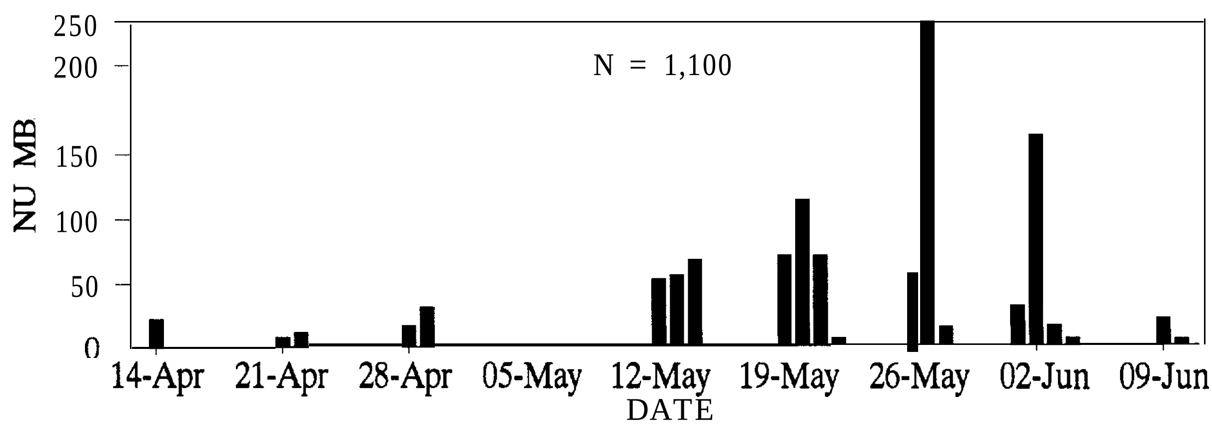

Figure S.-Number of chinook salmon juveniles PIT tagged by date in the Snake River between RK 205 and RK 290, 14 April to 10 June, 1992.

Weekly post-tagging mortality of PIT-tagged chinook salmon juveniles ranged from 0 to 22.7% from the week of 12 April to 7 June (Figure 6). The highest mortality occurred from 12 April to 13 May when we used unrinsed iodine disinfected tags and held salmon in minnow traps for 24-h after tagging. In the laboratory on 15 May, we determined that the quantity of iodine we used as an antibacterial treatment killed PIT-tagged fall chinook salmon juveniles when injected into their body cavities (Table 3). Mortality began 24 h after the fish were injected with iodine. After 96 h cumulative mortalities of injected and control fall chinook salmon were 52% and 0%, respectively. Weekly post-tagging mortality decreased to a range of 0 to 1.1% when we switched to alcohol disinfected blotted tags and a 15-min recovery period (Figure 6). No 24-h holding tests were done in the Snake River after switching to alcohol as a tag disinfectant.

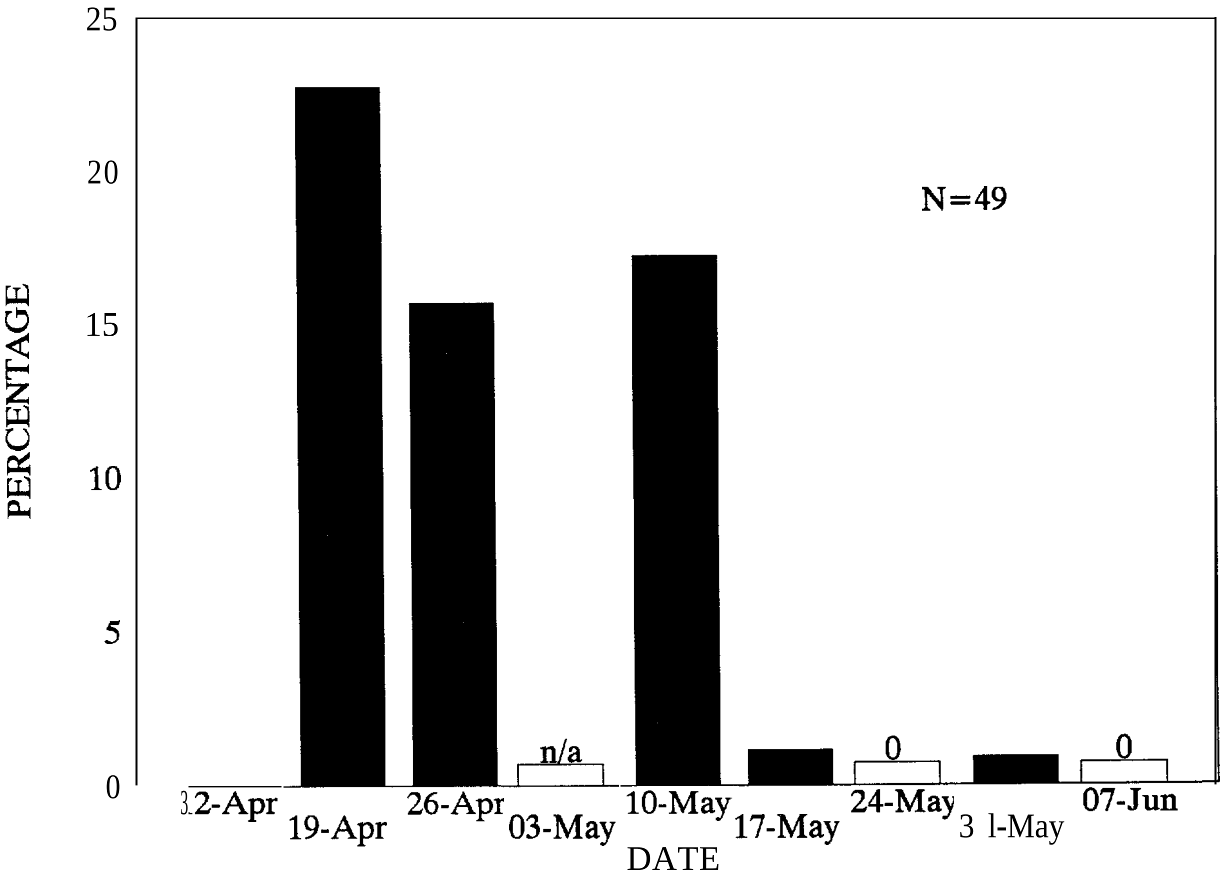

Figure 6.-Weekly post-tagging mortality of PIT-tagged chinook salmon juveniles 12 April to 7 June, 1993. Note that fish were held for 24-h after tagging in minnow traps from 12 April to 13 May after which they were released 15 min after tagging. No fish were tagged the week of 3 May.

Table 3.-Ninety-six hour mortality of hatchery fall chinook salmon injected with a 0.05 g solution of 50% iodine and control fish which were not injected with iodine, 15 May 1993.

Treatment	Sample size	Holding duration (h)	Daily mortality	Cumulative mortality (%)
Injected	25	24	0	0
		48	12	48
		72	1	52
		96	0	52
Control	33	24	0	0
		48	0	0
		72	0	0
		96	0	0

A total of 51 chinook salmon juveniles we PIT tagged were detected at Lower Granite Dam, of which 16 were diverted by the sliding gate. Electrophoresis validated 14 of the above 16 fish as fall chinook salmon and the remaining two as spring/summer chinook salmon (Table 4). The 14 fall chinook salmon juveniles grew an average of 1.0 mm/d (SD = ±0.3 mm/d; range = 0.3-1.5 mm/d) and had a mean FL of 111.2 ±11.2 mm.

The post-season upper size limit for fall chinook salmon provided a fairly accurate method to separate the data by chinook salmon race (Figure 7). Applying the post-season upper size limit to the FL of the 2,710 juvenile chinook salmon we seined and measured identified 2,056 as fall chinook salmon.

Systematic Samples

Systematic beach seining collected 1,309 of the 2,056 fall chinook salmon. Fall chinook salmon captured during systematic sampling ranged in FL from 34 to 99 mm (mean = 58 ±11 mm; Figure 8). Back calculated emergence timing estimates for the 1,309 fall chinook salmon ranged from 18 March to 25 May (Figure 9). The estimated pattern of emergence appears bimodal with an early peak on 31 March and a later peaks about 22 to 25 April.

Mean catch per unit effort (CPUE) of fall chinook salmon, by week from 29 March to 7 June, ranged from 0.3 to 8.5 (Figure 10). There was no marked change in CPUE the week of 10 May when we switched to a larger seine. The peak CPUE of 8.5 occurred the week of 17 May. Mean CPUE dropped quickly after the 17 May peak through the week of 7 June when we quit sampling. The overall 1992 mean CPUE was 2.6.

Table 4.-Data for chinook salmon juveniles PIT tagged in the Snake River, diverted at Lower Granite Dam, and analyzed by electrophoresis, 1992.

Tag code	Release date	Release length (mm)	Release weight (g)	Detection date	Detection length (mm)	Detection weight (g)	Days at Large	Race	Age	Growth rate (mm/d)
7F7D0E0947	30-Apr	76	4.2	23-Jun	117	16.4	53.6	Spring/summer		0.8
7F7D111443	02-Jun	99	11.6	18-Jun	110	14.5	15.6	Spring/summer		0.7
7F7D0E5D17	30-Apr	74	4.3	22-Jun	127	21.5	53.4	Fall		1.0
7F7D0E0048	13-May	89	7.5	30-Jun	126	23.6	47.9	Fall		0.8
7F7D0E4C6B	14-May	74		16-Jun	106	12.9	32.7	Fall		1.0
7F7D0E5A63	19-May	69	3	27-Jun	103	14.5	38.5	Fall		0.9
7F7D0F6730	20-May	63	3.5	21-Jul	136		61.6	Fall		1.2
7F7D0B3449	20-May	88	a.4	26-Jun	119	19.5	37.6	Fall		0.8
7F7D0F6451	20-May	60	2.1	07-Jul	110	15.8	47.7	Fall		1.0
7F7D08233C	21-May	75	4.3	16-Jun	99	9.9	25.7	Fall		0.9
7F7D0E107A	26-May	70	3.8	20-Jun	96	a.4	25.0	Fall		1.0
7F7D0B3149	27-May	70		30-Jun	101	11.2	34.4	Fall		0.9
7F7D0D6266	27-May	73	4.4	29-Jun	107	14.5	32.5	Fall		1.0
7F7D0D5303	04-Jun	86	7.4	28-Jun	116	17.4	24.3	Fall		1.2
7F7D0B317D	26-May	67	3.4	03-Jul	Ill		29.3	Fall		1.5
7F7D0F6E5D	02-Jun	95	10.3	17-Jun	100	11.0	15.6	Fall		0.3

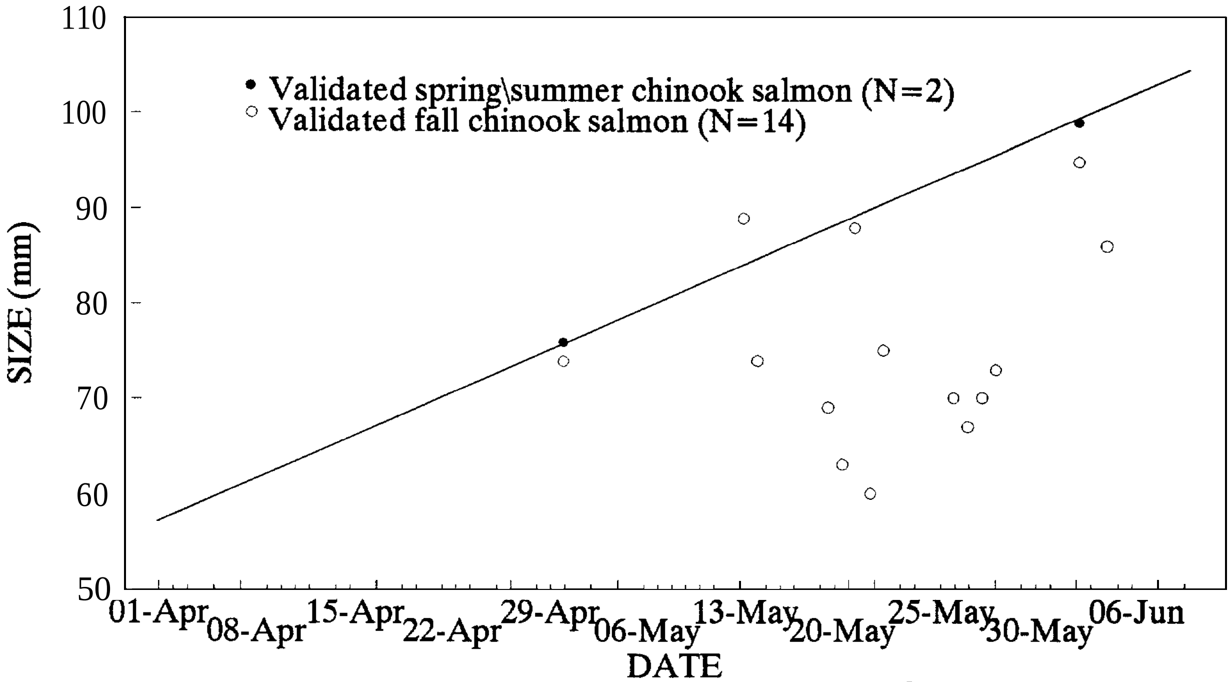

Figure 7.–Testing the applicability of the "post-season" size limit using chinook salmon juveniles which were seined and PIT tagged in the Snake River, diverted at Lower Granite Dam, and subjected to electrophoresis, 1992.

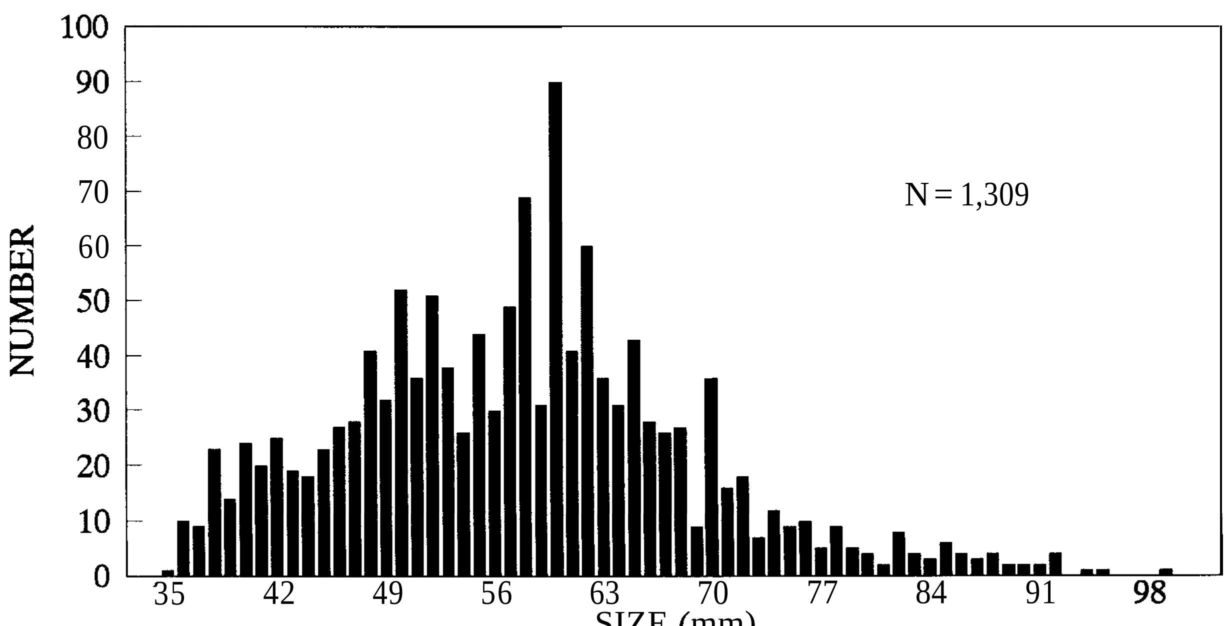

Figure S.-Length frequency distribution of fall chinook salmon seined from the Snake River by systematic sampling, 1 April - 10 June, 1992.

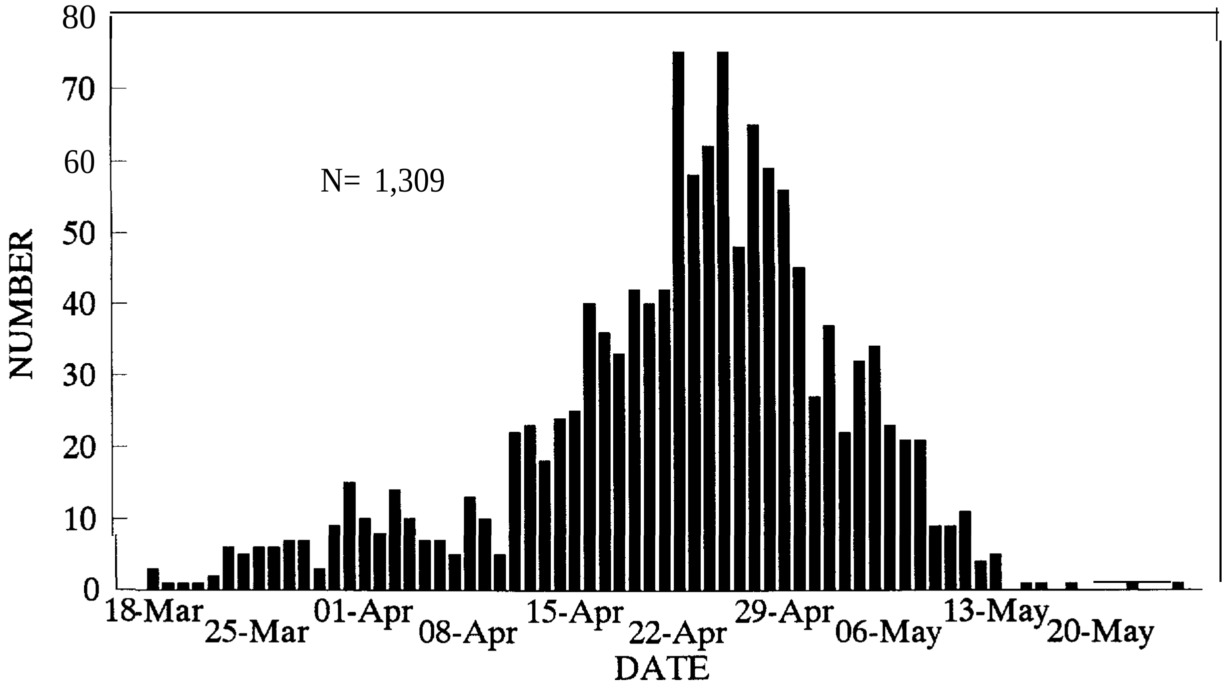

Figure 9.-Snake River fall chinook salmon emergence timing in 1992 back calculated using the release size of each fish, individual growth rates or the the average growth rate of 1.0 mm/d.

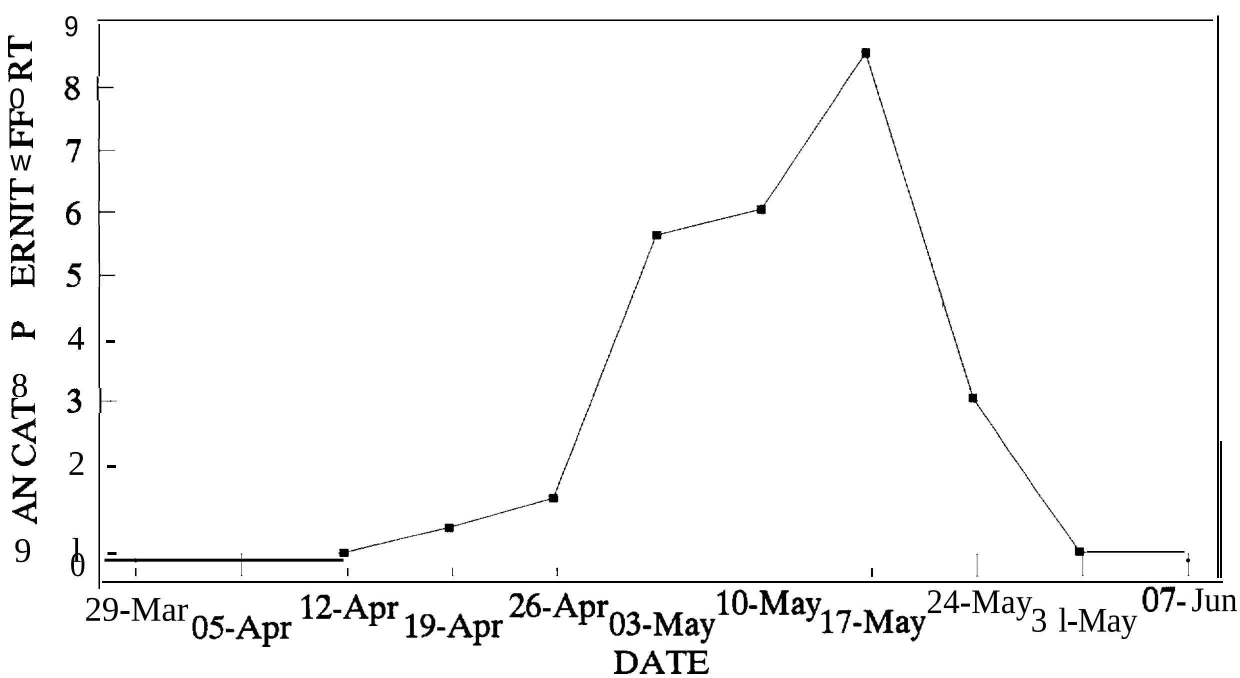

Figure 10.–Mean catch per unit effort of Snake River fall chinook salmon juveniles by sampling week, 1992.

The 1992 mean CPUE of fall chinook salmon varied by site (identified as a river kilometer; Figure 11). The lowest 1992 mean CPUE occurred at RK 346, where no fall chinook salmon were caught and the highest overall CPUE of 8.1 occurred at RK 282 followed by 6.5 at RK 248.

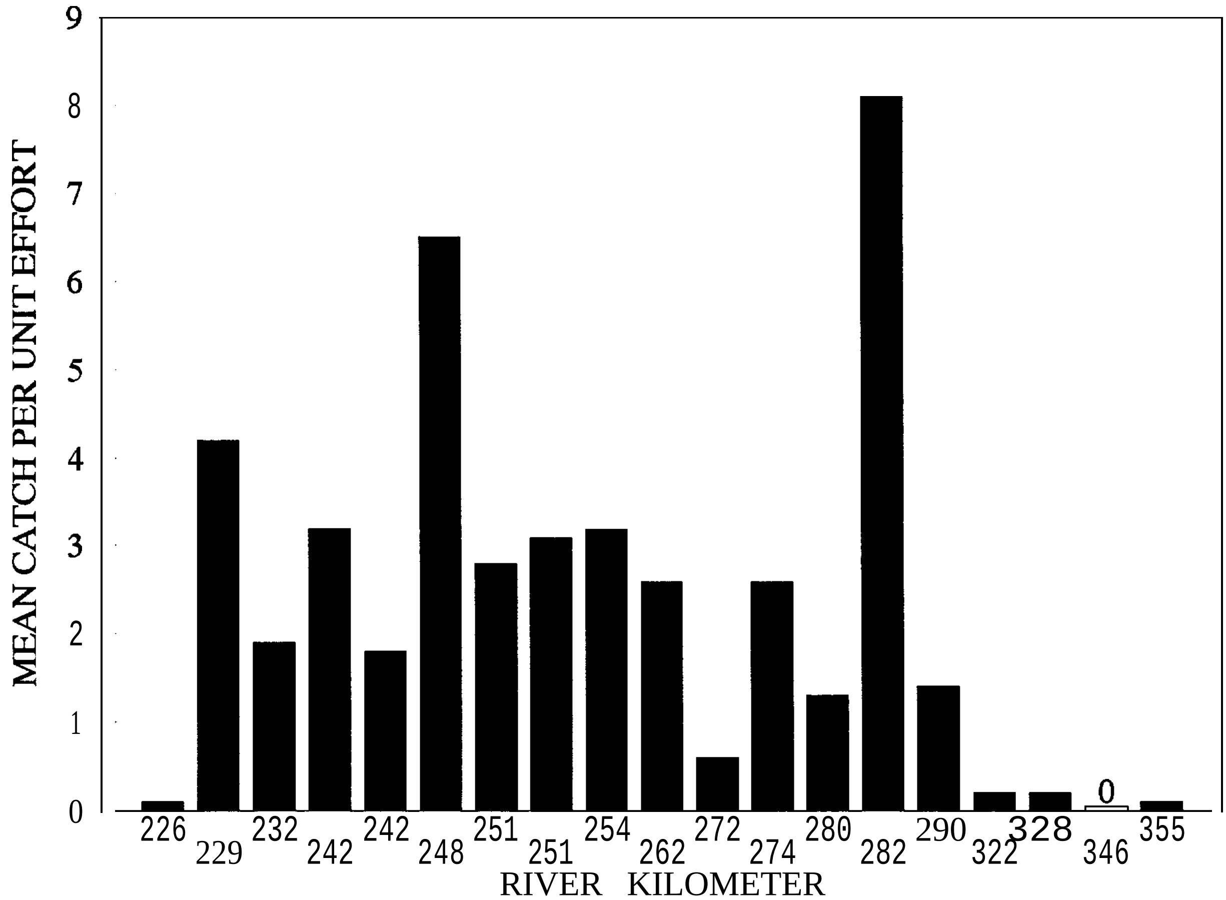

Figure 11.- **Mean** overall catch per unit effort of Snake River fall chinook salmon juveniles by river kilometer, 1 April - 11 June, 1992.

Combined Grab and Systematic Samples

The total number of fall chinook salmon we PIT tagged in combined grab and systematic samples was 947. The 947 fall chinook salmon from the combined sample were released between the dates of 15 April and 10 June (Figure 12). The peak release of PIT-tagged fall chinook salmon from the combined sample was on 27 May (N = 230). PIT-tagged fall chinook salmon from the combined sample were released between RK 226 and RK 290; most releases were at RK 251 (N = 220; Figure 13). The mean FL of PIT-tagged fall chinook salmon at release in 1992 was 70 ±9 mm and fish ranged from 60 to 99 mm FL (Figure 14).

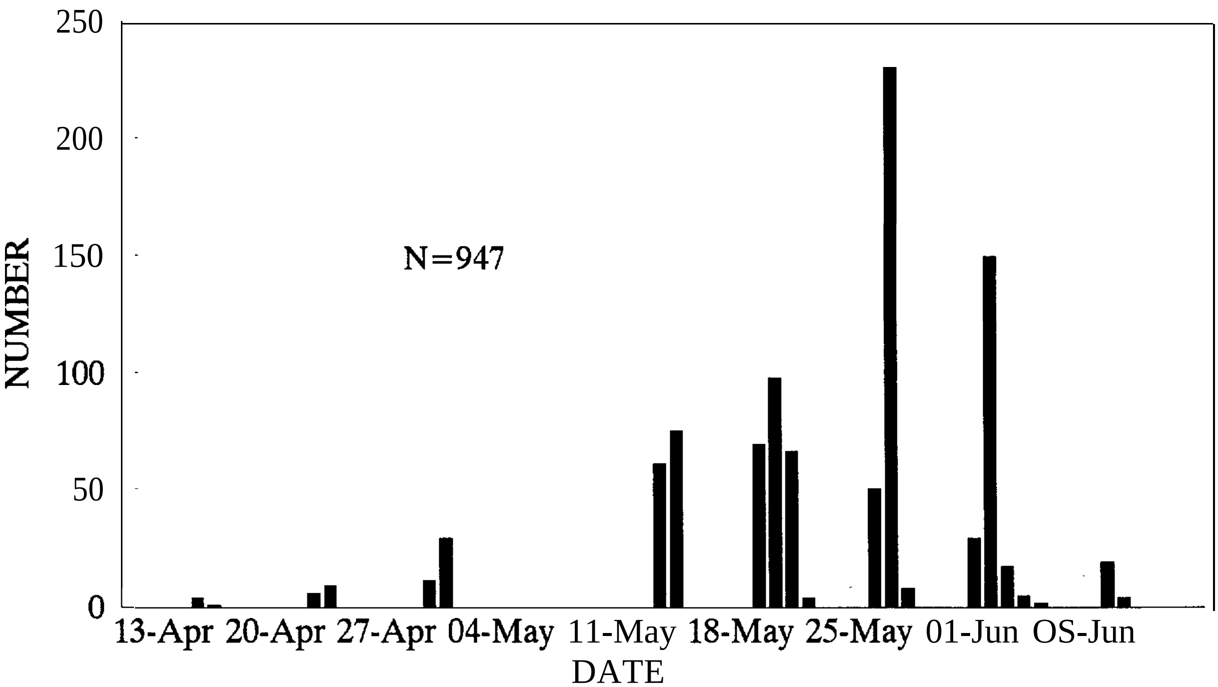

Figure 12.–Number of PIT-tagged fall chinook salmon released by date in the Snake River through combined systematic and grab samples collected between RK 211 and RK 290, 1992.

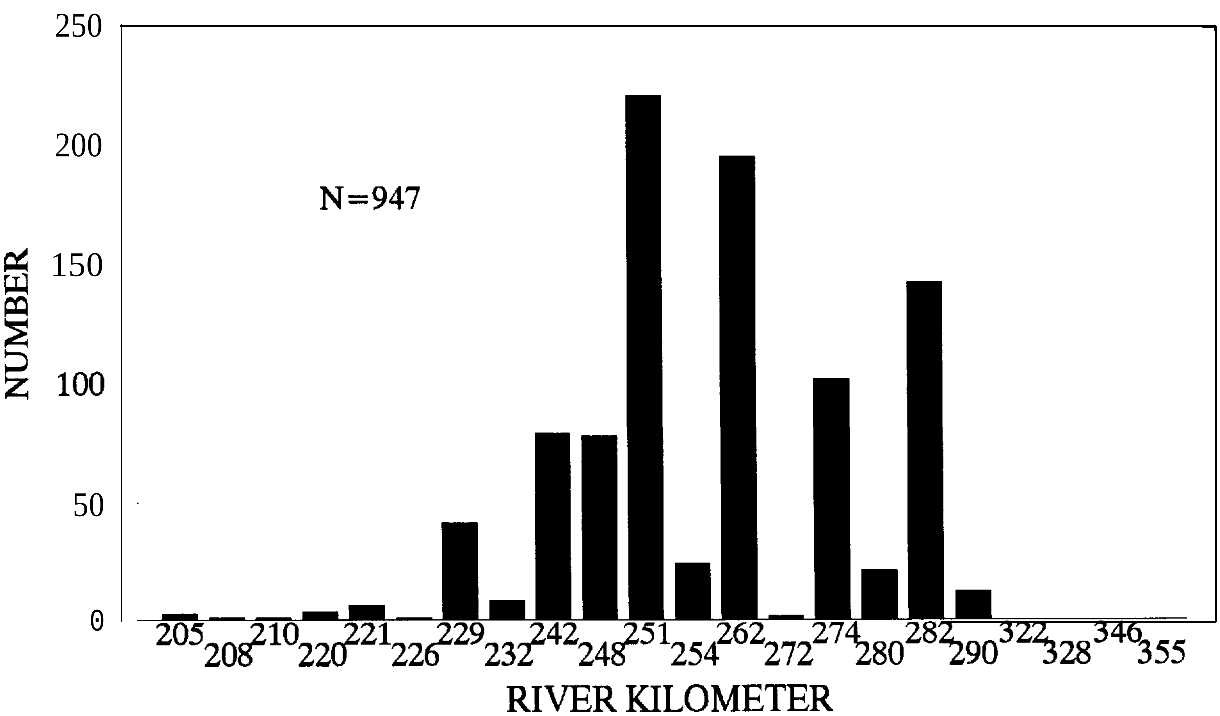

Figure 13.–Number of Snake River fall chinook salmon PIT tagged by river kilometer by combined systematic and grab sampling, 15 April - 10 June, 1992.

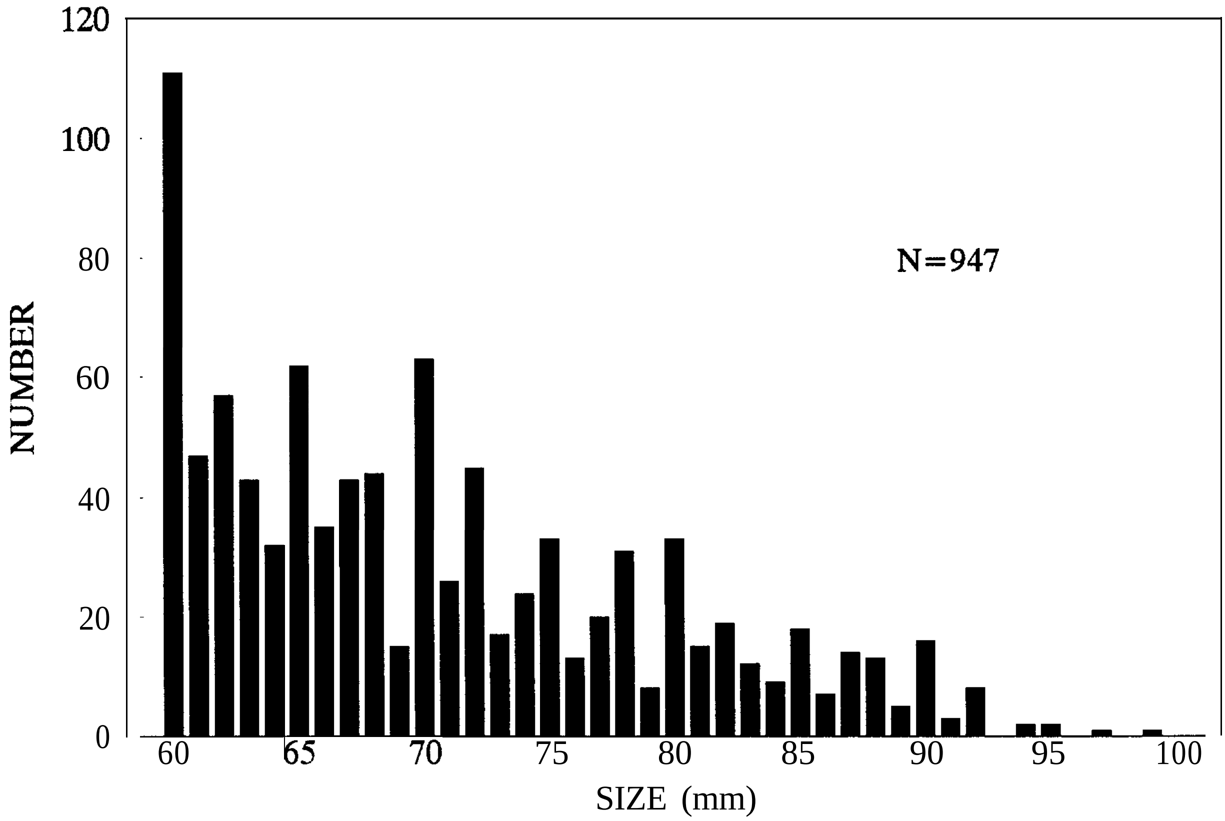

Figure 14.–Length frequency distribution of fall chinook salmon PIT tagged in the Snake River by combined systematic and grab sampling, 1992.

Through combined sampling we recaptured 66 PIT-tagged fall chinook salmon once and 3 twice (recapture rate = 7.3%; Table 5). Recapture interval ranged from 1 to 27 d with the most common interval of 5 d. Seven PIT-tagged fall chinook salmon were recaptured downstream of their original tagging site. Downstream movement ranged from 1 to 30 km.

Thirty-three PIT-tagged fall chinook salmon were detected at Lower Granite Dam between 4 May and 21 July, 1992 (Figure 15). Detection of tagged fall chinook salmon at Lower Granite peaked on 23 June (N = 5) and the median date of arrival was 22 June. PIT-tagged fall chinook salmon required from 3.5 to 61.6 d to reach Lower Granite Dam after the date of their last release (Figure 16) and their emigration rates to the dam averaged 3.6 km/d (SD = ±1.8 km/d, range = 1.1-9.3 km/d; Figure 17).

Table 5.-PIT-tagged fall chinook salmon juveniles recaptured by beach seine in the Snake River, 1992.

Tag code	Release				First recapture				Second recapture				Time interval (d)	Kilometers travelled downstream
	date	length (mm)	weight (g)	kilometer	date	length (mm)	weight (g)	kilometer	date	length (mm)	weight (g)	kilometer		
7F7D0F6A43	01-Jun	82		262	02-Jun	83	0	232					1	30
7F7D0B3005	19-May	64	1.7	280	27-May	70	3.9	262					8	18
7F7D0E0443	30-Apr	61	2.9	274	27-May	85	6.4	262					27	12
7F7D0E0C02	27-May	77	4.8	274	01-Jun	81	0	262					5	12
7F7D0E3620	27-May	62	2.7	290	03-Jun	70	0	282					7	8
7F7D112E52	02-Jun	90	7.5	250	IO-Jun	97	11.4	248					8	2
7F7D0B3301	26-May	60	2.5	251	02-Jun	67	3.4	250					7	1
7F7D0F7003	14-May	70		282	19-May	70	3.6	282					5	
7F7D100364	21-May	76	4.6	251	26-May	77	5.8	251					5	
7F7D0F6757	21-May	76	4.9	251	26-May	78	5.9	251					5	
7F7D0F712A	21-May	87	8.3	251	26-May	92	9	251					5	
7F7D103055	21-May	61	2.4	251	26-May	67	3.5	251					5	
7F7D0E472E	21-May	84	6.4	251	26-May	88	8.2	251					5	
7F7D0F656D	20-May	62	2.7	248	26-May	66	3.3	248					6	
7F7D0E577E	13-May	60	2.6	251	21-May	68	2.8	251					8	
7F7D0F6137	21-May	62	2.8	251	26-May	67	3.5	251					5	
7F7D0F7119	21-May	66	3.3	251	26-May	71	4.4	251					5	
7F7D0F6669	21-May	62	3.2	251	26-May	67	3.8	251					5	
7F7D0E5B08	14-May	60		282	19-May	63	2.6	282					5	
7F7D0F741F	El-May	78	5.5	251	26-May	83	6.9	251					5	
7F7D0B1506	14-May	66		282	19-May	67	2.7	282					5	
7F7D0E476E	13-May	80	6.8	251	21-May	88	7.4	251					8	
7F7D0B3224	14-May	60		274	19-May	62	2.5	274					5	
7F7D0E4809	14-May	67		282	19-May	75	4.1	282					5	
7F7D0E4844	14-May	74		282	19-May	77	4.8	282					5	
7F7D0E4458	14-May	60		282	19-May	62	2.8	282					5	
7F7D0B217F	14-May	70	4.7	280	19-May	72	4.5	280	20-May	73	4.4	242	6	
7F7D0E027B	14-May	74		282	19-May	78	4.7	282					5	
7F7D0B352D	14-May	61	0	274	19-May	63	2.5	274					5	
7F7D0F600E	13-May	63	3.5	254	21-May	72	3.9	254					8	
7F7D0B1916	14-May	70		282	19-May	73	3.8	282	27-May	84	0	282	13	
7F7D0E5011	14-May	61		282	19-May	62	2.7	282					5	
7F7D0E4767	14-May	71		282	19-May	70	3.5	282					5	
7F7D0F607F	14-May	67	3.2	229	20-May	68	3.6	229					6	
7F7D0E472B	14-May	62		282	27-May	78	0	282					13	
7F7D0E4779	14-May	65	3.3	282	27-May	77	4.7	274					13	
7F7D0B317D	26-May	67	3.4	251	04-Jun	75	5.1	251					9	
7F7D10186F	02-Jun	66	3.6	250	09-Jun	72	4.1	250					7	

Table 5. (Continued

Tag code	Release				First recapture				Second recapture				Time interval (d)	Kilometers travelled downstream
	date	Length (mm)	weight (g)	kilometer	date	length (mm)	weight (g)	kilometer	date	length (mm)	weight (g)	kilometer		
7F7D0E5B4E	27-May	75	4.7	274	03-Jun	82	6.3	274	04-Jun	84	6	262	8	
7F7D0E3B22	27-May	60		282	03-Jun	65	0	282					7	
7F7D0B3512	14-May	71		282	03-Jun	90	0	282					20	
7F7D0E526D	13-May	79	6.7	251	04-Jun	107	14.5	251					22	
7F7D0F7066	20-May	66	3.6	242	0f-Jun	82	6.4	242					13	
7F7D101753	02-Jun	65	3.5	250	09-Jun	74	4.8	250					7	
7F7D0F2B3C	27-May	80	5.7	262	01-Jun	85	0	262					5	
7F7D101D51	02-Jun	75	5.2	250	09-Jun	82	5.6	250					7	
7F7D112826	02-Jun	81	5.7	250	09-Jun	87	6.8	250					7	
7F7D10050E	02-Jun	78	6.4	250	09-Jun	90	8.9	250					7	
7F7D0F6426	20-May	62	3	242	09-Jun	81	5.6	242					20	
7r7D0B3415	27-May	61	2.5	274	03-Jun	70	3.9	274					7	
7F7D0E1B13	19-May	70	3.8	282	27-May	80	0	282					8	
7F7D0F2F7F	27-May	78	5.5	262	01-Jun	80	0	262					5	
7F7D0D6F79	27-May	72	4.5	262	01-Jun	77	0	262					5	
7F7D10003B	27-May	68	2.9	262	01-Jun	72	0	262					5	
7F7D0F6E6C	02-Jun	73	4.7	242	09-Jun	78	5	242					7	
7F7D0E471F	13-May	60	2.2	262	27-May	74	4.3	262					14	
7F7D0B2840	19-May	64	2.7	274	27-May	70	3.7	274					8	
7F7D0B2D1E	19-May	64	2.8	282	27-May	72	4.2	282					8	
7F7D0B265E	14-May	64		282	27-May	75	3.6	282					13	
7F7D0E3530	27-May	70	4.2	262	01-Jun	75	5.7	262					5	
7F7D0F2D43	27-May	75	5.2	262	01-Jun	80	0	262					5	
7F7D0E1E49	27-May	72	4.2	262	01-Jun	78	0	262					5	
7F7D0E2333	27-May	72	3.8	262	01-Jun	77	0	262					5	
7F7D0E3C22	27-May	74	4.3	262	01-Jun	80	0	262					5	
7F7D0E237E	27-May	68	3.4	262	01-Jun	73	0	262					5	
7F7D0E1B37	14-May	68		282	19-May	71	3.7	282					5	

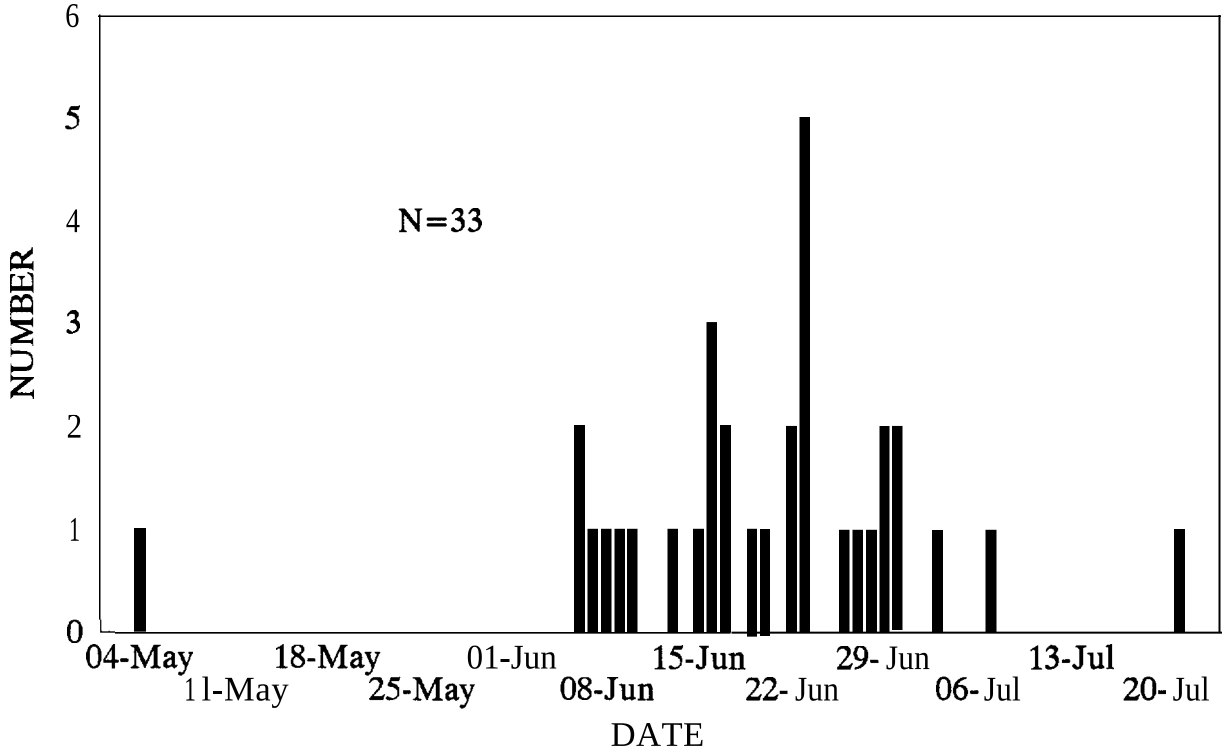

Figure 15.–PIT-tag detection numbers for fall chinook salmon juveniles released in the Snake River in 1992.

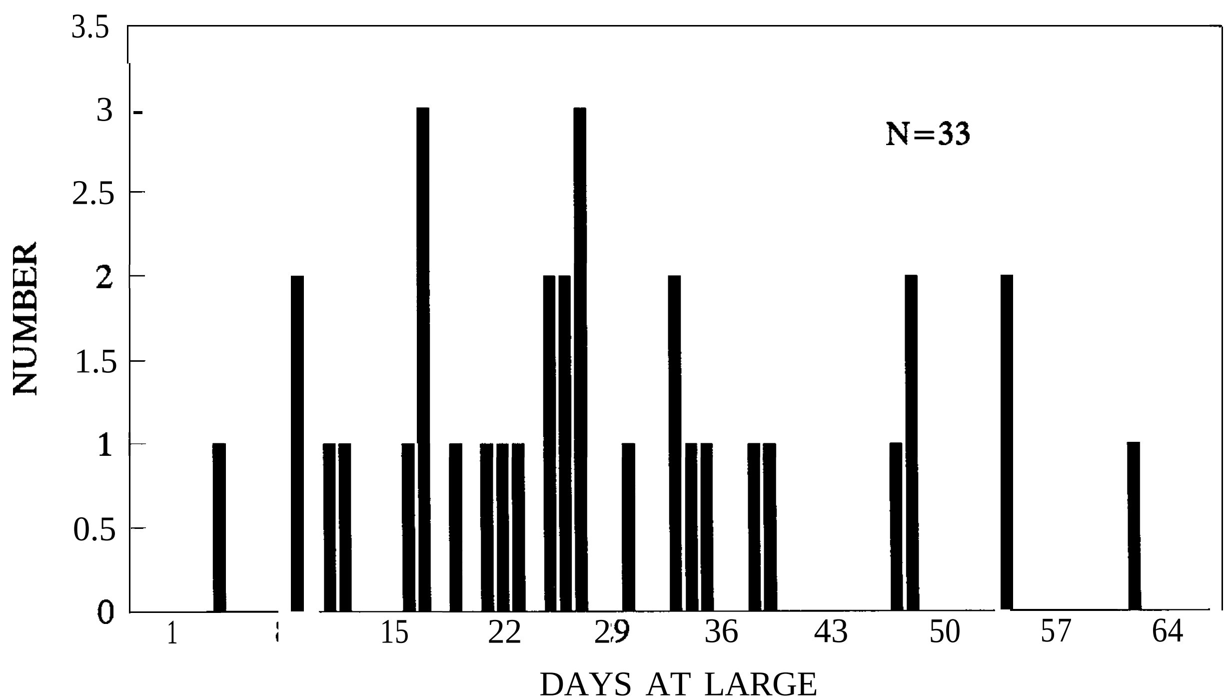

Figure 16.–Number of days PIT-tagged Snake River fall chinook salmon juveniles were at large in 1992 before detection at Lower Granite Dam.

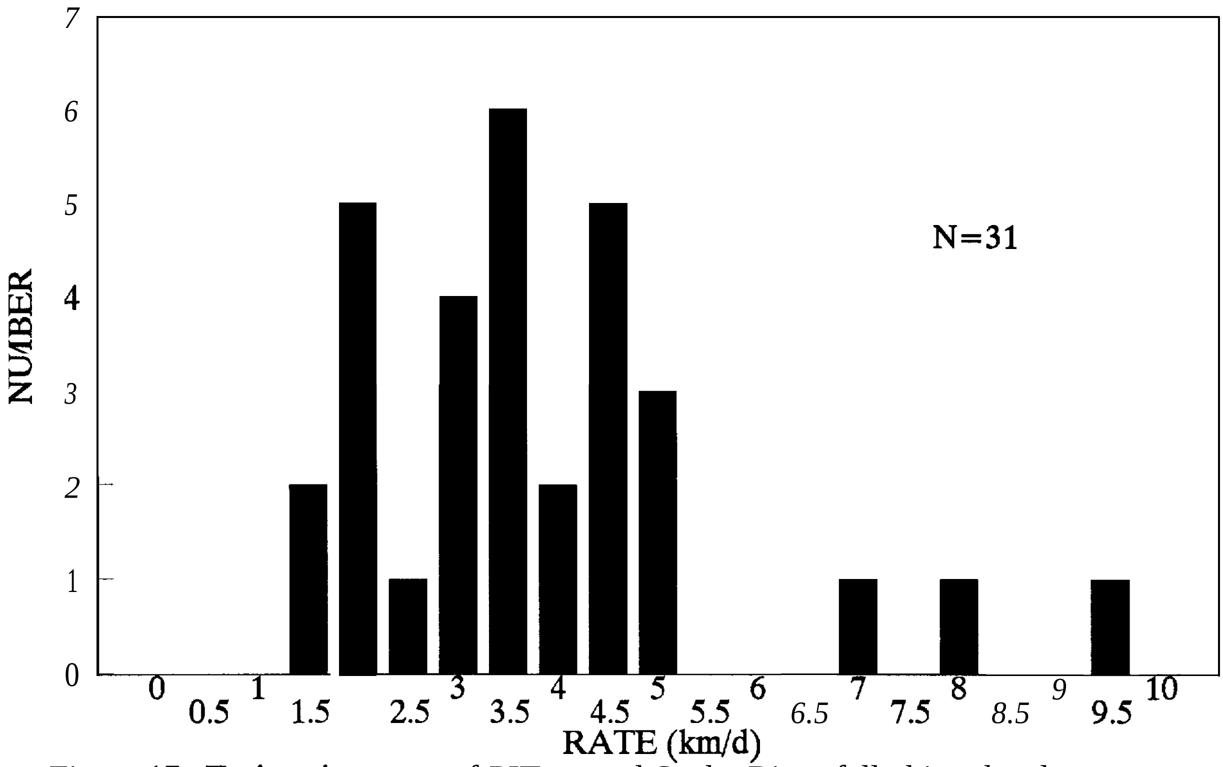

Figure 17.–Emigration rates of PIT-tagged Snake River fall chinook salmon detected at Lower Granite Dam in 1992. Note that two outliers were removed from this figure after regression analysis.

Influence of Flow, Temperature, and Size on Emigration Rate

Pearson correlations (SYSTAT 1990) indicated there was collinearity between emigration flow and emigration temperature (Pearson Correlation = -0.885; Table 6). After removing emigration temperature from the analysis, 72% of the variability in emigration rate in 1992 could be explained by emigration flow, release temperature, and release size (Table 7).

The relation of emigration rate to the emigration flow, release temperature, and release size for 1992 was:

$$\text{RATE} = -24.261 + 0.184\ \text{MIGRFLO} + 1.073\ \text{RELTEMP} + 0.052\ \text{RELSZ}$$

Where: RATE = emigration rate to Lower Granite Dam (km/d);
MIGRFLO = emigration flow (KCFS);
RELTEMP = release temperature (°C); and
RELSZ = release size (mm).

Table 6.-Pearson correlation matrix for the emigration rate analysis of Snake River fall chinook salmon juveniles, 1992.

	MIGRFLOW	MIGRTEMP	RELTEMP	RELSZ
MIGRFLO	1.000			
MIGRTEMP	-0.885	1.000		
RELTEMP	-0.614	0.609	1.000	
RELSZ	-0.200	0.161	0.502	1.000

Table 7.-SYSTAT multiple regression output (forward stepwise) for relation among emigration rate (MIGRRATE), emigration flow (MIGRFLO), release temperature (RELTEMP), and release size (RELSZ). Data were collected by PIT tagging Snake River fall chinook salmon juveniles, 1992.

DEP VAR=RATE N=31 MULTPL R=0.845 SQUARED MULTPL R=0.715
ADJUSTED SQUARED MULTPL R=.683 STD ERROR OF ESTIMATE=1.033

VARIABLE	COEF.	STD ERROR	STD COEF	TOLERANCE	T	P(2 TAIL)
CONSTANT	-24.261	3.598	0.000	.	-6.743	0.000
MIGRFLO	0.184	0.035	0.689	0.607	5.217	0.000
RELTEMP	1.073	0.191	0.839	0.473	5.609	0.000
RELSZ	0.052	0.022	0.288	0.729	2.393	0.024

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
REGRESSION	72.144	3	24.048	22.540	0.000
RESIDUAL	28.806	27	1.067		

Furthermore, from data in Table 7, we concluded that the 1992 response in emigration rate was higher with increases in release temperature (standardized coefficient = 0.839) than with increases in emigration flow (standardized coefficient = 0.689), or release size (standardized coefficient = 0.288).

Using 1992 averages for release size, release temperature, and emigration flow, this relation predicts that a 77 mm fall chinook salmon, released in 15.4°C nearshore water, would have emigrated 5.5 km/d under flows of 50 KCFS compared to 3.6 km/d under the 39.9 KCFS flow that actually occurred (53% faster under 50 KCFS; Figure 18).

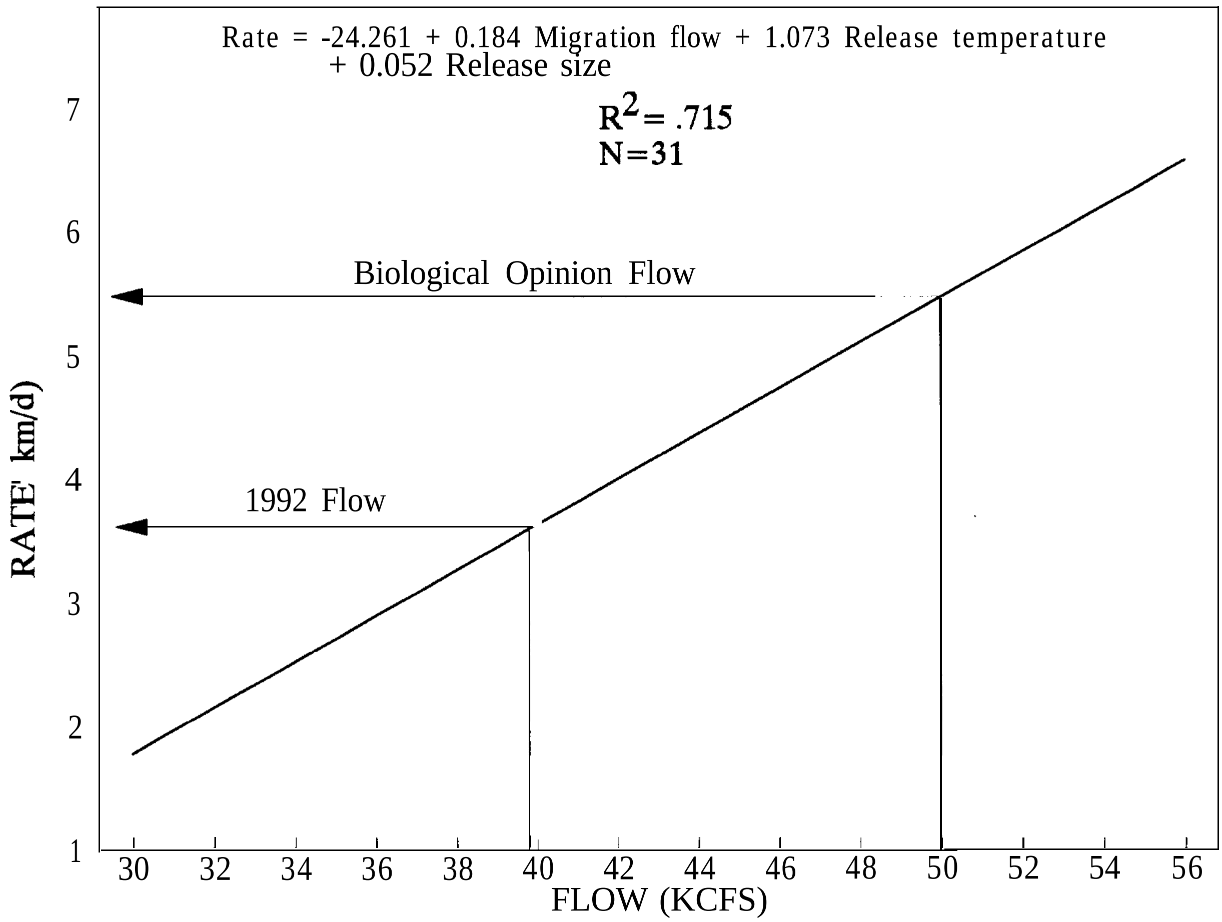

Figure 18. Predicted emigration rates for a 77 mm PIT-tagged fall chinook salmon released in 15.4 degrees Celsius water under the average 1992 flow conditions at Lower Granite Dam and under the Biological Opinion flow fo 50 KCFS.

Discussion

Differences in fall chinook salmon early life history were documented between 1991 and 1992. Peak fall chinook salmon fry emergence in 1992 was back calculated to late April, about 30 d earlier than in 1991 (Connor et al. 1993). After emerging in 1992, fall chinook salmon reared in nearshore areas from mid-March to early June with a mid-May peak based on CPUE calculated from systematic samples. In 1991, PIT-tagged fall chinook salmon rearing in near-shore areas appeared to have begun in May and extended through mid-July (Connor et al. 1993). The highest 1991 catch of fall chinook salmon occurred at RK 242 about 3 km below Big Bench Point where about 43% of all redds were counted in brood year 1991 (Garcia et al. in this report). We had the highest CPUE at RK 282 in 1992, while most fall chinook salmon spawning in brood year 1992 was documented below this site (Garcia et al. in this report). High CPUE at RK 282 may have been the result of fish concentrating in one area since rearing habitat may be less available in the higher gradient reaches above the mouth of the Grande Ronde River. Some fall chinook salmon juveniles in the Snake River showed fidelity to individual rearing areas prior to emigration in both 1991 and 1992. In 1991, about 8% (53 of 650) of PIT-tagged fall chinook salmon were recaptured within 1 to 21 d after tagging (Connor et al. 1993). Only one of the tagged fall chinook salmon was recaptured away from the original tagging site. In 1992, we recaptured about 7% (69 of 947) of the fall chinook salmon tagged, and seven of the fish had moved downstream. The differences in fall chinook salmon early life history between 1991 and 1992 were undoubtedly related to flows and water temperatures, however an in depth analysis of this topic is beyond the scope of this annual report.

Fall chinook salmon arrival at Lower Granite Dam was a summer event in 1992 as in most years, but the arrival pattern was truncated. The 1991 detection pattern of PIT-tagged fall chinook salmon at Lower Granite Dam was protracted, extending into early September, while no PIT-tagged fall chinook salmon were detected after 20 July in 1992. The truncation of the 1992 PIT-tag detection pattern may have been due to decreased survival of later emigrating PIT-tagged salmon, poor fish guidance efficiency at Lower Granite Dam, or a combination of both. It is likely that any of these explanations would be correlated to the relatively lower flows and warmer water temperatures of 1992.

Fall chinook salmon emigration rate **was** faster in 1992 (3.6 $\pm$1.8 km/d) than in 1991 (2.3+1.0 km/d), even after we adjusted the 1991 data set for a minimum emigration size (Connor et **al.** 1993). At first glance, we thought that faster 1992 emigration rates may have been due to the truncated detection pattern of PIT-tagged fall chinook salmon at Lower Granite Dam, since the' 1992 data set lacked late arriving PIT-tagged emigrants which can have slower than average emigration rates. However, the mean emigration rate of the first 50% of PIT-tagged fall chinook salmon in 1991 (2.9 ±0.9 km/d) was still slower than the overall 1992 rate. We concluded that fall chinook salmon emigrated faster in 1992 than in 1991.

Faster emigration rates in 1992 may be explained by differences in release water temperature and flow between years. Water temperature increased and flow decreased earlier in 1992 than in 1991. Fall chinook salmon emigration behavior evolved under the descending limb of summer flows when water is warming rapidly, so faster emigration rates under less optimum rearing conditions would be a survival adaptation. In the case of summer emigrants, the pattern of change in temperature and flow may be as significant a determinant of emigration rate, as a given temperature or flow volume.

The 1992 emigration rate analysis indicated that of the variables tested, release temperature had the greatest effect on emigration rate of PIT-tagged fall chinook salmon followed closely by flow. Conversely, flow had greater effect than release temperature in 1991. The role of fall chinook salmon release size was also different between 1991 and 1992. Release size accounted for 53% of the variability in emigration rate in the 1991 data and by adjusting the data set to a minimum emigration size we were better able to relate emigration rate to emigration flow and release temperature. Therefore, we theorized that in 1991 fall chinook salmon juveniles did not actively migrate until they grew to a minimum size (Connor et al. 1993). Release size had **a** positive significant effect on 1992 emigration rate ($r^2 = 0.32$; $p = 0.001$), but its influence was lowest of the three independent variables tested. We concluded that the 1992 pattern of an early decrease in flow accompanied by the rapid rise in temperature may have triggered fall chinook salmon emigration with somewhat less dependence on size.

Prior to 1991 there was no summer flow augmentation for natural Snake River fall chinook salmon emigration (Connor et al. 1992). We used our regression model to assess the benefits of increasing flow over fall chinook salmon emigration in 1992. Our model predicted that if the 50 KCFS flow recommended by the NMFS's Biological Opinion (1993) **was** implemented in 1992, the average fall chinook salmon emigrant would have spent less time reaching Lower Granite Dam.

In summary, we seined 1,309 fall chinook salmon in systematic samples in 1992. Estimated fall chinook salmon fry emergence ranged from 18 March to 25 May with a 25 April peak. Weekly CPUE of fall chinook averaged 2.6 (range 0.3-8.5) and peaked on 20 May. We PIT tagged and released 1,100 chinook salmon juveniles of which 947 were considered as fall chinook salmon (87%) on the basis of post season race separation. We tagged fall chinook salmon in the Snake River from 14 April through 10 June with a 27 May peak. About 7% of all tagged fall chinook salmon were recaptured by seine; most at the original site of tagging. Mean emigration rate from release sites in Hells Canyon to Lower Granite Dam was 3.6 km/d with peak and median dates of passage on 23 and 22 June, respectively. Using multilinear regression we estimated that emigration rate was significantly influenced by temperature, flow, and fish size. It is important to realize that the low population level of Snake River fall chinook salmon dictated small sample sizes for analyses. These preliminary analyses and interpretations will be refined with the collection of additional data in the future.

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CHAPTER SIX

Nearshore Habitat Use by Subyearling Chinook Salmon in the Columbia and Snake Rivers

by

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Introduction

Currently, little published information exists on habitat requirements for subyearling fall chinook salmon *Oncorhynchus tshawytscha* rearing in the Columbia and Snake rivers. Subyearling chinook salmon have been reported in shoreline areas of the Snake (Mains and Smith 1964) and Columbia rivers (Mains and Smith 1964; Becker 1973; Dauble et al. 1980; Dauble et al. 1989) and in backwater nearshore areas of the Columbia and Snake river reservoirs (Zimmerman and Rasmussen 1981; Bennett et al. 1990, 1991, 1993). Subyearling chinook salmon may reside along river margins because maximum growth is achieved through the interaction of food resources, velocity, and temperature (Becker 1973). The role of these variables in the dispersal, rearing, and migratory stages of subyearling chinook salmon is unknown, but needs to be determined to effectively conserve and enhance fall chinook salmon populations. Furthermore, such information is necessary to protect important rearing habitats in future proposals to modify reservoir and riverine habitats by dredging, filling, bank stabilization, flow management, and water diversion.

The goal of this study is to identify and describe the characteristics of rearing habitats used by naturally produced subyearling chinook salmon in riverine reaches and in main-stem reservoirs. Preliminary results described in this report were obtained during the first year of **a** five-year study.

Study Area

The 1992 study area included two reaches in the Columbia River from river kilometer (RK) 508 to RK 530 in McNary Reservoir and from RK 563 to RK 581 in the Hanford Reach (Figure 1). The Snake River was sampled between RK 227 and RK 358 (see Connor et al. this report for map). River kilometer information was obtained from the National Oceanic and Atmospheric Administration for McNary Reservoir, from the United States Geological Survey (USGS) 7.5 minute topographic maps for the Hanford Reach, and from the U.S. Army Corps of Engineers (COE) navigation charts for the Snake River.

Methods

Methods for the collection and handling of fish captured in the Snake River are described by Connor et al. (in this report). The methods outlined in this chapter describe the procedure for site selection, capture and handling of fish in the Columbia River reaches. Habitat variables were measured in the same manner for all reaches except where noted.

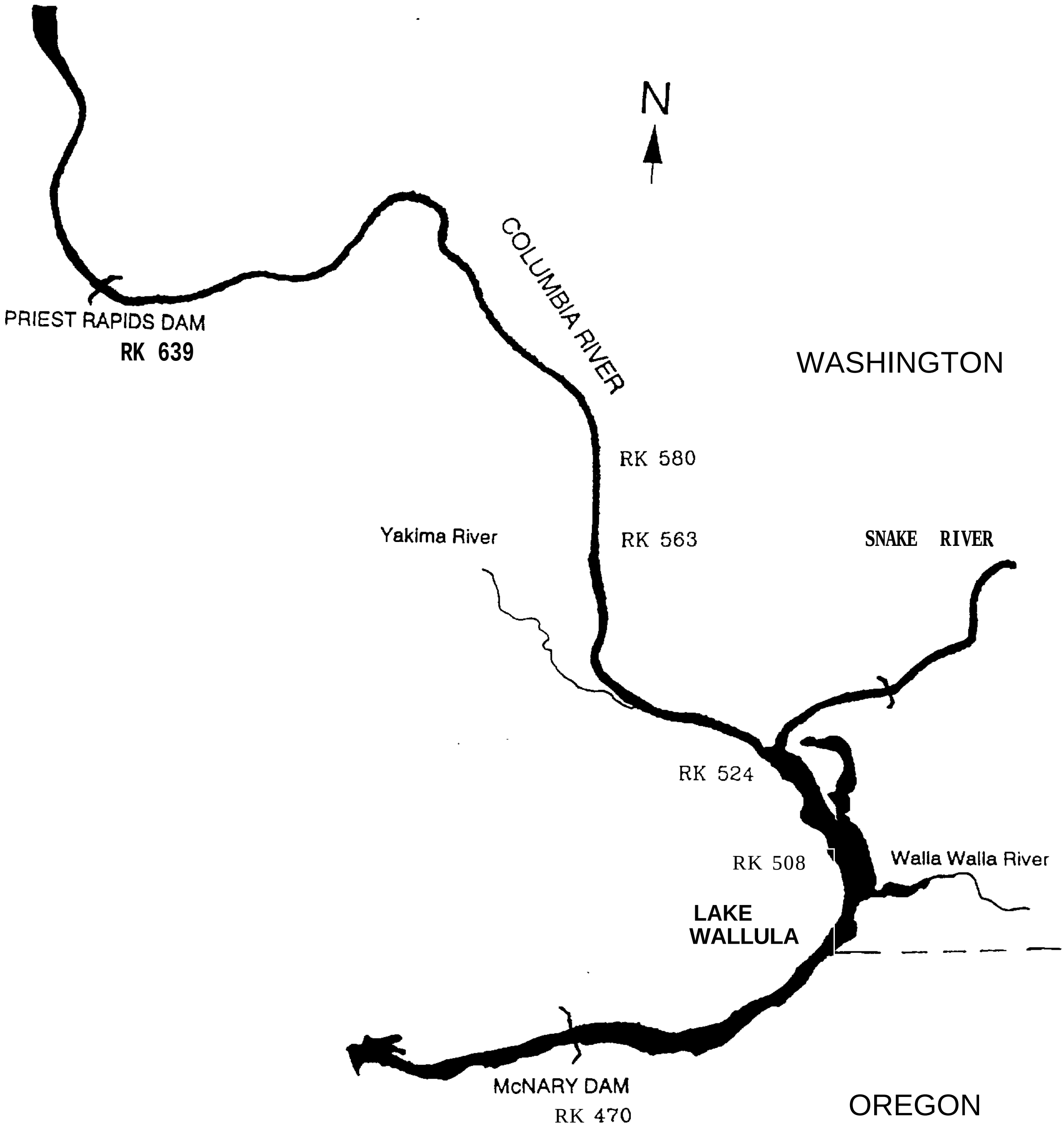

Figure 1.— Map showing the location of McNary Reservoir and Hanford Reach habitat sampling areas. Sampling areas in McNary Reservoir extends from RK 508 upstream to RK 523 and in the Hanford Reach from RK 563 to RK 580.

The sites selected were conducive to beach seining and represent combinations of habitat variables available to subyearling chinook salmon. Sites were selected on both banks of the river channel and on side channels. Both linear and complex shorelines were selected in backwater and main channel areas.

All sites in McNary Reservoir (36) and the Hanford Reach (16) were identified by a stake placed above the high water mark. This ensured that the same location would be sampled throughout the season and allowed for measurement of changes in the water elevation at each site. Once all sites were selected, blocks containing six or more sites were established and the sampling order randomized within each block. A single seine haul was made at each site in McNary and Hanford reaches during each week of sampling. All sites were sampled during daylight hours. Sites in McNary and Hanford reaches were sampled from May to August.

Seining

The beach seine used in McNary Reservoir was 30.5 m x 2.4 m with 0.48 cm mesh, 2.4 m^3 bag and 15.2 m leads. A polypropylene rope was wrapped around the leadline to increase its diameter and reduce the incidence of snagging and collecting large substrate. The seine was set from the bow of a 5.5 m boat by backing 15.2 m from shore and then setting the seine parallel to the shoreline in an upstream direction. Once the net was set, both ends of the seine were pulled simultaneously to the shore by the leads. This sampled an area of about 460 m^2 at each site in McNary Reservoir. The beach seine used in the Hanford Reach was of the same design as used in McNary Reservoir except it was 22.9 m long and sampled an area of about 345 m^2.

Catch

Fish caught in each seine haul were processed immediately to minimize stress. If more than 40 subyearling chinook salmon were captured, a subsample of approximately 30 were randomly removed and processed. The subsample was anesthetized with 26 mg per liter of tricaine methanesulfonate (MS-222), fork lengths (L) measured to the nearest millimeter, and weights (W) were recorded to the nearest 0.1 g. Remaining salmonids and incidental fish caught were identified to the lowest taxonomic group possible, enumerated, and released. Based on length frequency information obtained from each week of sampling, subyearling chinook salmon were separated from yearling chinook salmon. Mean catch and mean length of subyearling chinook salmon were computed per seine haul for each week of sampling. All hauls were used to compute means in the Columbia River reaches. Only hauls made at 10 sites consistently sampled every week beginning the week of 20 April were used to compute mean catch in the Snake River. Length and weight data obtained from subyearling chinook salmon were plotted and a curve fitted by the power equation, $W=aL^b$ (Ricker 1958).

Because all habitat seining activities were performed during daylight hours, a pilot diel study was conducted to determine if subyearling chinook salmon catch remained constant in the shoreline areas during day and night. Sixteen sites along a shoreline on Foundation Island (RK 518-518.5) in McNary Reservoir were randomly sampled. A total of 71 beach seine hauls were made over three days in mid June. Catch and light were analyzed to determine whether they were significantly correlated ($P \le 0.05$). Mean catches were calculated and grouped into five light categories, then statistically analyzed using analysis of variance and Tukey's studentized range test (SAS Institute 1988). Differences were considered statistically significant when $P \le 0.05$.

Habitat Measures

Habitat variables that fluctuated on a daily basis were measured for each seine haul. Light and turbidity were measured before each net set. Light was measured above the water surface and 0.5 m below the water surface using an International Light 1400A light meter.. Turbidity of water collected 15 cm below the surface was measured with a Hach 2100P turbidity meter. After seining each site, distance from the stake to the waterline was measured. The midpoint of the seine site was determined by measuring half the seine length upstream from the stake. At midpoint and 1 m from the shoreline, water temperature was measured to 0.1°C. Water velocity was measured at the midpoint 7.6 m and 15.2 m from the shoreline using a Swoffer Model 2100 or Marsh McBirney Model 2000 velocity meter. Temperature and dissolved oxygen were measured at the midpoint 15.2 m from the shoreline and at 1 m below the surface using a YSI Model 59 dissolved oxygen meter.

Thermographs were set to record water temperatures at one hour intervals in a main channel (RK 516.0), side channel (RK 512.0), and backwater area (RK 510.7) of McNary Reservoir. A single thermograph was set in a main channel area of the Hanford Reach (RK 561.8). Thermographs were set 15 m from the shoreline in approximately 2-3 m of water.

The physical characteristics of the seining sites were surveyed after completing beach seining. Depth, substrate, embeddedness and vegetation were mapped for McNary Reservoir and Hanford Reach sites. An electronic total station was used to measure distances to points where habitat characteristics were measured within the beach seine sites. At each point the substrate was visually assessed and assigned a code according to a Wentworth classification modified from Orth (1983). Descriptions for visually evaluating substrate embeddedness were obtained from Platts et al. (1983). Aquatic vegetation was assessed for species, numbers of plants per meter and height. Habitat and positional information for each point were entered into a spreadsheet and transferred to a raster based geographic information system (GIS). In GIS, habitat was mapped using 1 m^2 cells. Relative water elevation for each seine haul was calculated from the stake distance. Elevation was used to determine the nearest wetted row of cells which became the beginning point of the beach seine. Once the shoreline point of each beach seine haul was known, the surveyed habitat variables were estimated using the GIS record.

Results

Catch of Subyearling Chinook Salmon

During the habitat study, a total of 18,858 subyearling chinook salmon were captured in McNary Reservoir; 2,972 were caught in the Hanford Reach; and 1,322 were caught in the Snake River. Connor et al. (this report) estimated 1,309 of the subyearlings caught in the Snake River were of the fall chinook salmon race using a post season size limit criteria. Subyearling chinook salmon made up 79% of the combined salmonid and incidental catch in McNary Reservoir and 63% of the combined catch in the Hanford Reach from May through August. Incidental fish caught in McNary Reservoir and the Hanford Reach are reported in Appendix 6.

A total of 169 beach seine hauls in McNary Reservoir, 73 hauls in the Hanford Reach and 272 hauls in the Snake River were made during the habitat study. Success in capturing one or more subyearling chinook salmon in a haul varied between reaches. In McNary Reservoir 61% of the hauls succeeded in capturing subyearlings (102 hauls), in the Hanford Reach 68% succeeded (50 hauls), and in the Snake River 50% succeeded (136 hauls).

The mean weekly catch per seine haul for McNary Reservoir, Hanford Reach, and the Snake River peaked in May then decreased throughout the summer (Figure 2; Appendix 7). The highest mean number of subyearling chinook salmon captured per seine haul (682) occurred in McNary Reservoir during the week of 12 May 1992. Catches were lower in the Hanford Reach than in McNary Reservoir during all weeks sampled with a peak of 153 juvenile chinook salmon captured during the week of 25 May. Subyearling chinook salmon were not captured in nearshore areas in August in either McNary Reservoir or Hanford Reaches. Peak mean catch of 159 subyearling chinook salmon occurred during the week of 3 May in the Snake River.

Subyearling chinook salmon in the Snake River maintained the highest mean fork length for every week sampled in comparison to Columbia River reaches (Figure 3; Appendix 8). Mean fork length of subyearling chinook salmon in McNary Reservoir was consistently higher than mean fork length in the Hanford Reach.

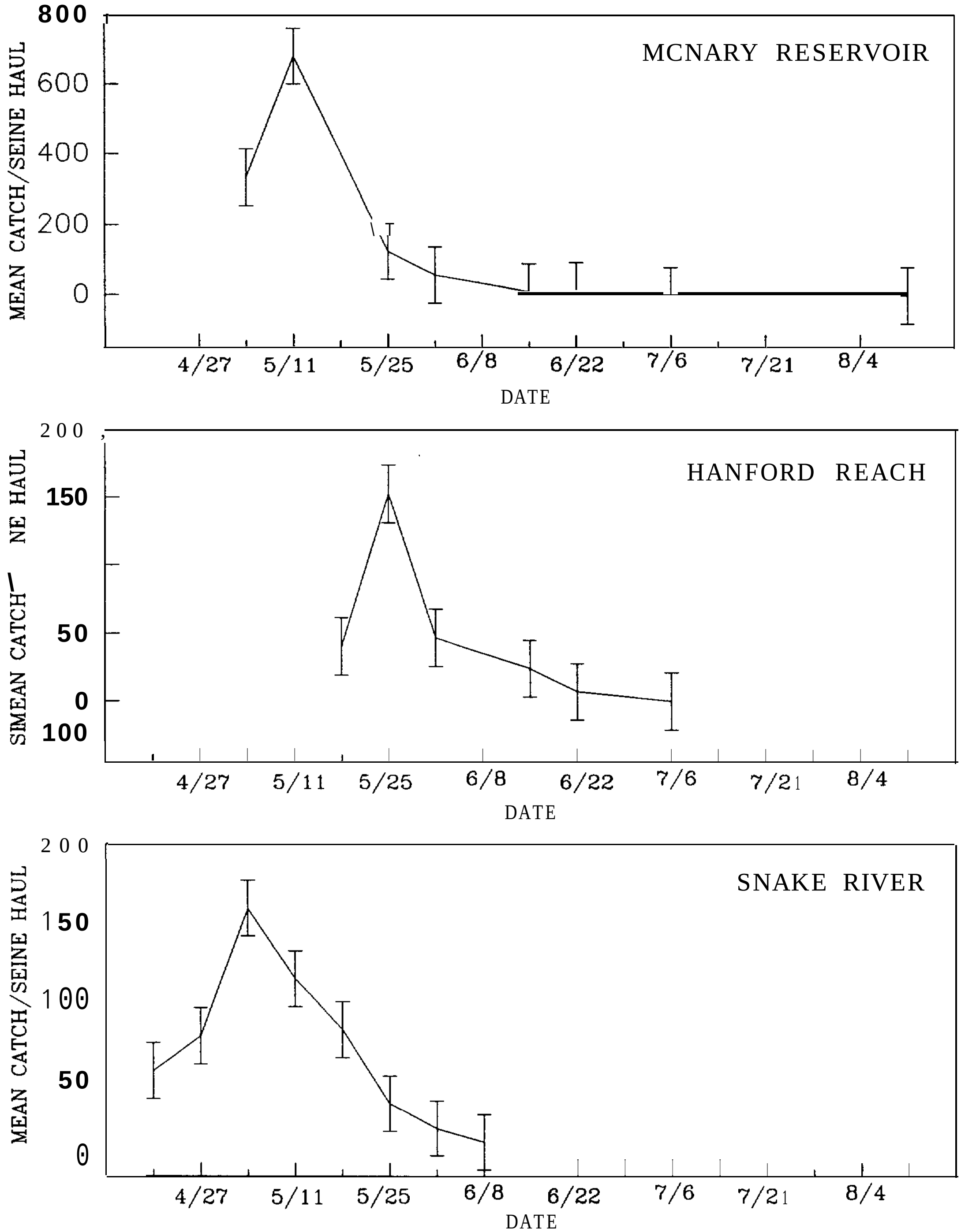

Figure 2.-Mean catch (± se) of subyearling chinook salmon caught by beach seine during one week sampling intervals in **McNary Reservoir and the Hanford Reach of the Columbia River,** Washington and in the Snake River, Idaho, Oregon, and Washington.

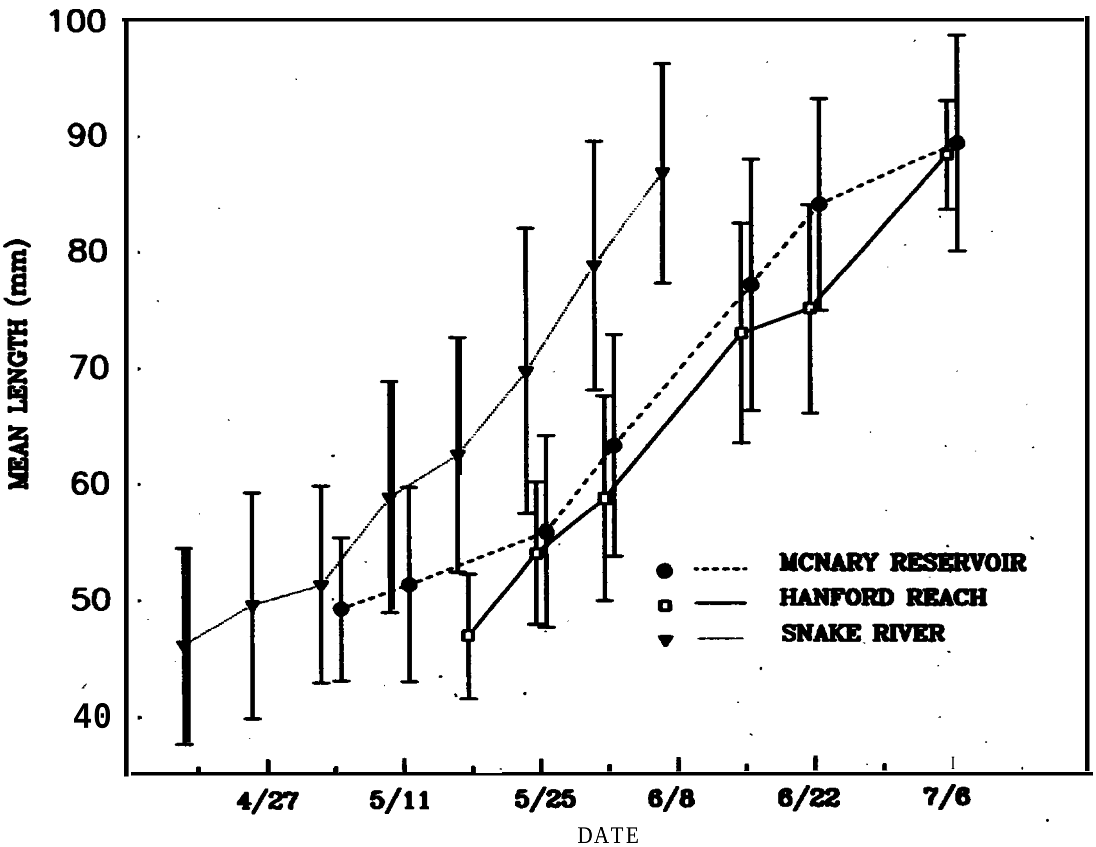

Figure 3.—**Mean** fork length (± sd) of **subyearling chinook salmon caught in McNary Reservoir and the Hanford Reach of the** Columbia **River,** Washington and in the Snake River, Idaho, Oregon, and Washington.

The length-weight curves for subyearling chinook salmon were similar for the two riverine reaches (Figure 4). The curve for McNary Reservoir had a larger exponent value indicating higher measured weight for a given length of subyearling chinook salmon.

Diel Catch

A total of 10,511 subyearling chinook salmon were caught during the diel study. Low numbers of subyearling chinook salmon were caught during the night (Figure 5). Catch increased immediately following sunrise (0515 hour) and decreased at sunset (2045 hour). Catch was significantly correlated with light ($r = 0.52$) (Figure 5). The hypothesis that mean catch for night and day categories was the same was rejected. Mean catch from day categories were not significantly different from each other nor were night categories significantly different from each other. Since no significant difference was found between the morning, midday and evening periods, the habitat data collected during these day periods were combined for analysis.

Habitat

For each seine haul, a GIS mapping procedure was used to produce a map containing defined strata for the surveyed habitat variables (Figure 6). Catch of subyearling chinook salmon was compared to the effort associated with various depths, velocities, temperatures, and substrates.

Most effort in McNary Reservoir was expended in shallow water sites (<1.5 m) and low water velocity (<0.05 m/s) (Figures 7 and 8). Few subyearlings were caught in sites where water depth 15.2 m from the shore was <0.5 m. Highest mean catch per seine haul was observed in sites with depths 0.5-l m at 7.6 m from the shoreline, and 0.75-1.75 m at 15.2 m from the shoreline. No relationship could be discerned between velocity and mean catch over the range in velocities presented. Daily temperature fluctuations measured by thermograph in nearshore areas had a range of 1.5°C (Figure 9). Highest mean catch per seine haul occurred at temperatures between 13.0-14.9°C at both 1 m and 15.2 m from the shore (Figure 10). No subyearling chinook salmon were caught when temperatures exceeded 26.7°C at 1 m from the shoreline or 21.9°C at 15.2 m from the shoreline. Catch of subyearling chinook salmon was not related to percent of fine substrate (Figure 11).

In the Hanford Reach, seining effort was distributed more evenly for depth, but no trends in the average catch per seine haul were obvious (Figure 12). Highest effort was expended in low velocities (<0.05 m/s) at 7.6 m and 15.2 m from shore and resulted in the highest catch of subyearling chinook salmon (Figure 13). No relationship could be discerned between velocity and mean catch. Daily temperature fluctuations measured by

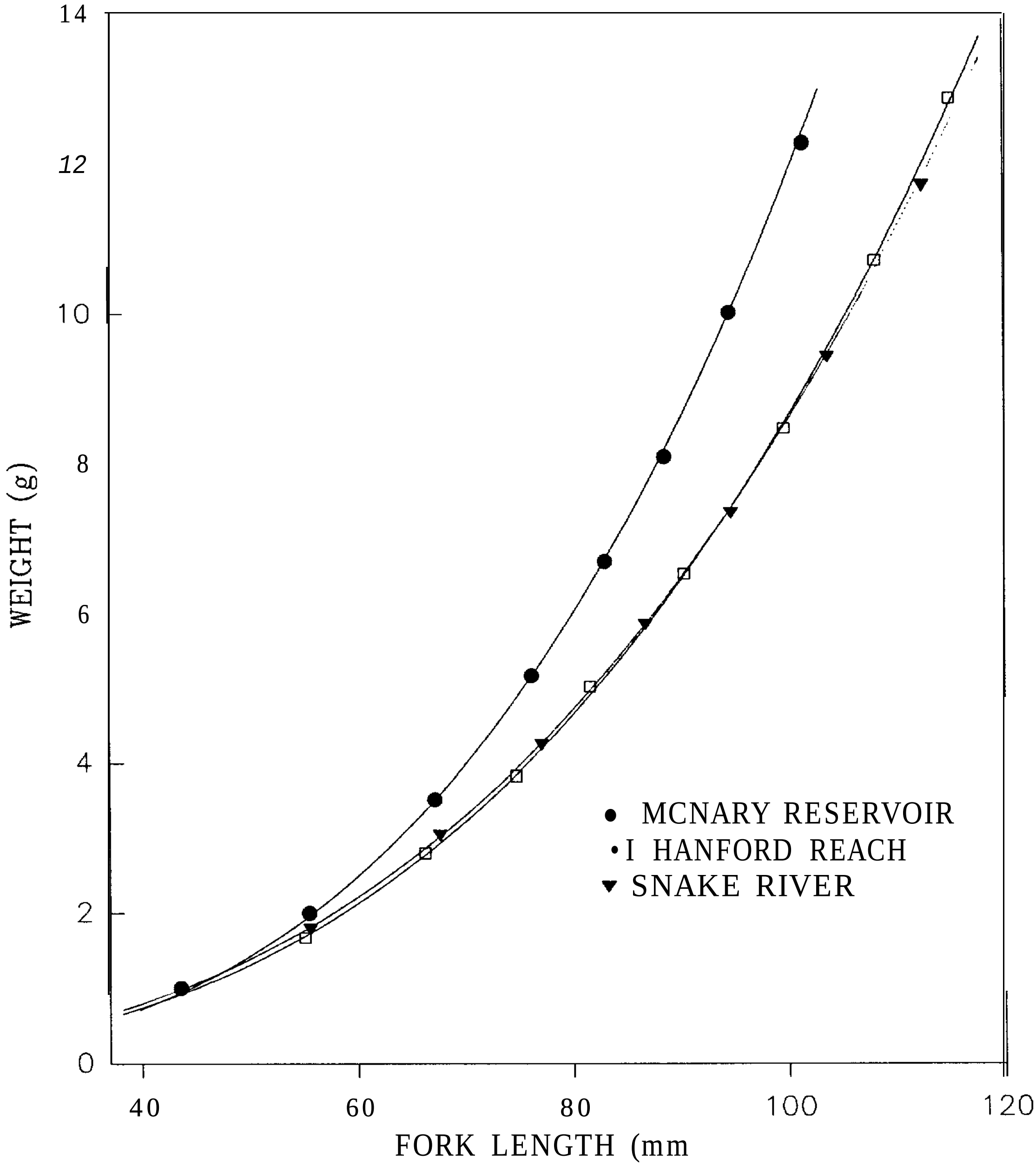

Figure 4.—Fitted curves for length and weight of all subyearling chinook salmon caught during 1992 in McNary Reservoir and the Hanford Reach in the Columbia River, Washington and in the Snake River, Idaho, Oregon, and Washington.

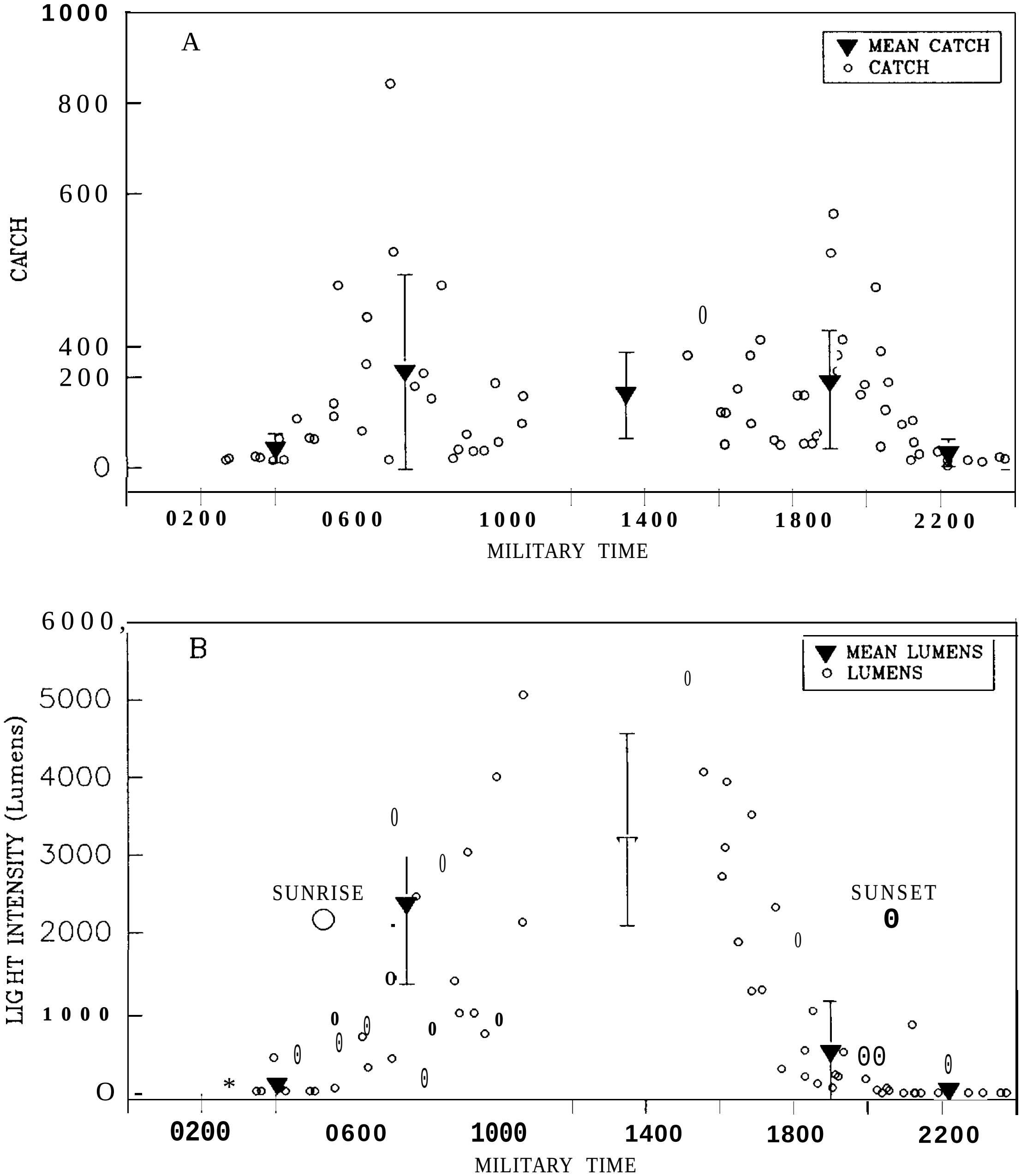

Figure 5.- (A) Catch of subyearling chinook salmon and (B) light intensities in McNary Reservoir. The catch and light intensities were grouped into five time catagories and means calculated. Means are displayed as triangles with corresponding standard deviations.

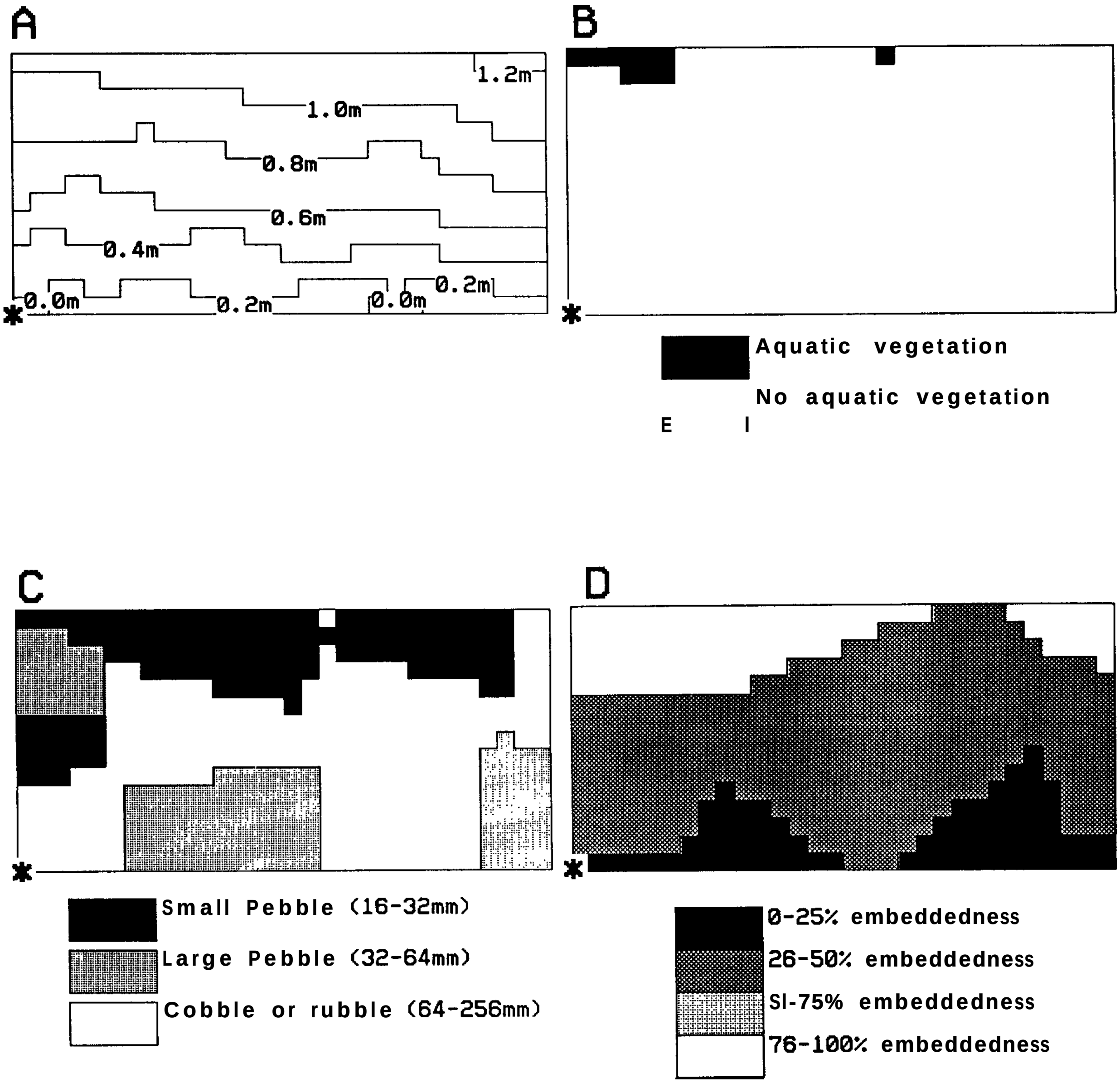

Figure 6.— Example of maps generated by GIS for determining areas of surveyed habitat variables (A) depth, (B) aquatic vegetation, (C) dominant substrate, and (D) embeddedness. Star (*) represents position of stake.

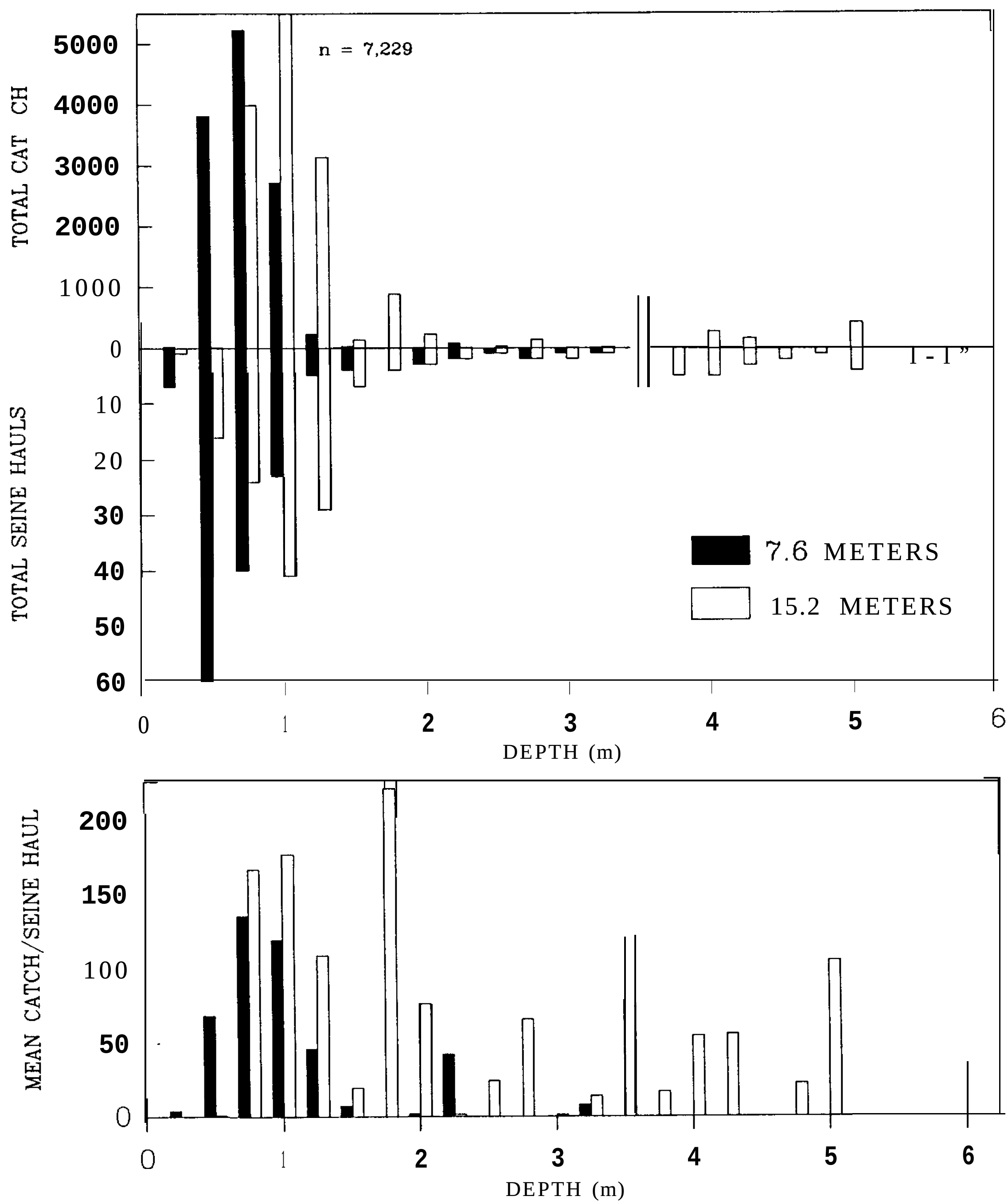

Figure 7.— Total catch, total seine hauls and mean catch/seine haul of subyearling chinook salmon. Depth was measured at 7.6 m and 15.2 m from the shoreline in McNary Reservoir of the Columbia River, Washington.

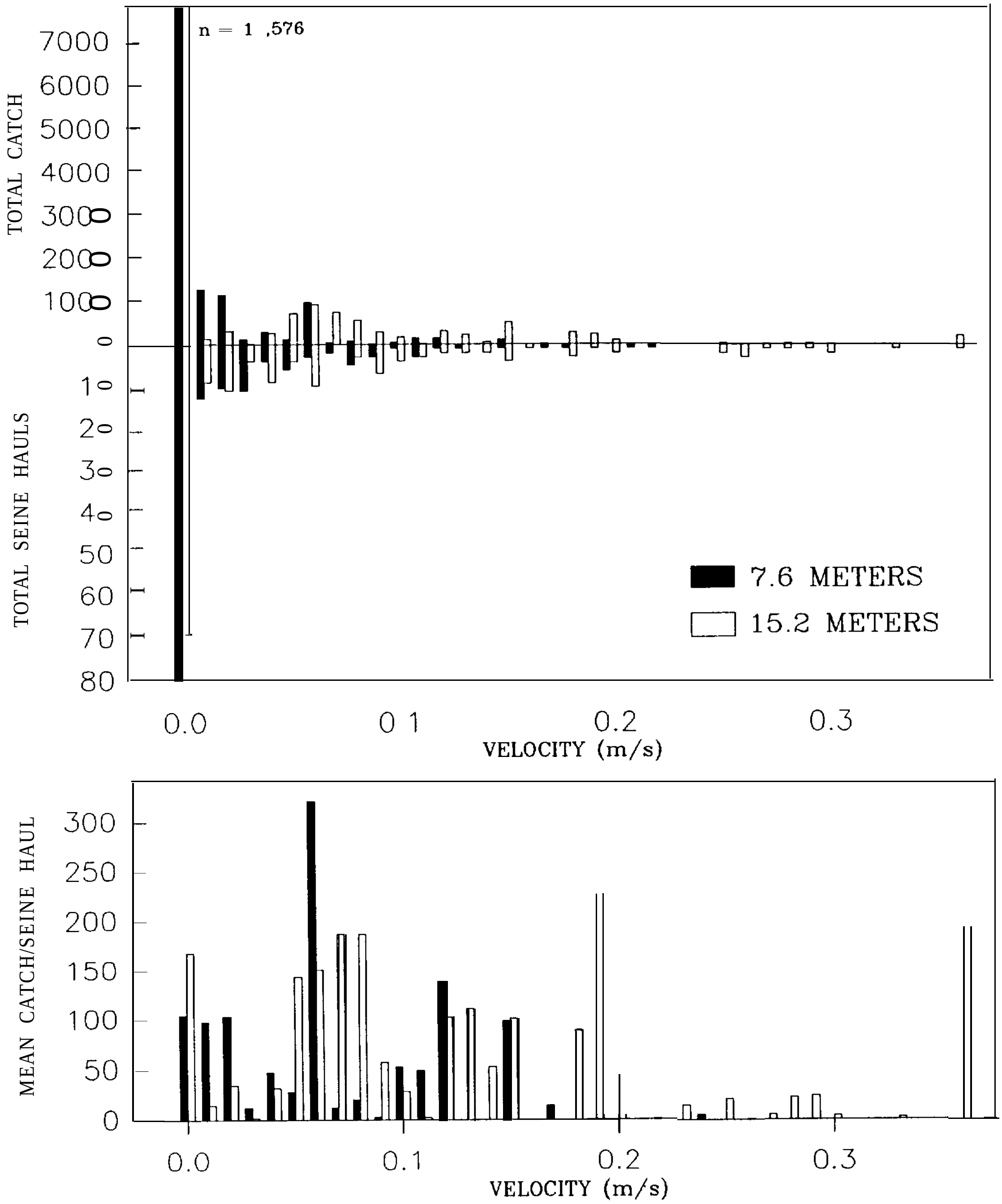

Figure 8.—Total catch, total seine hauls, and mean catch/seine haul of subyearling chinook salmon. Velocity was measured at 7.6 m and 15.2 m from the shoreline in McNary Reservoir of the Columbia River, Washington.

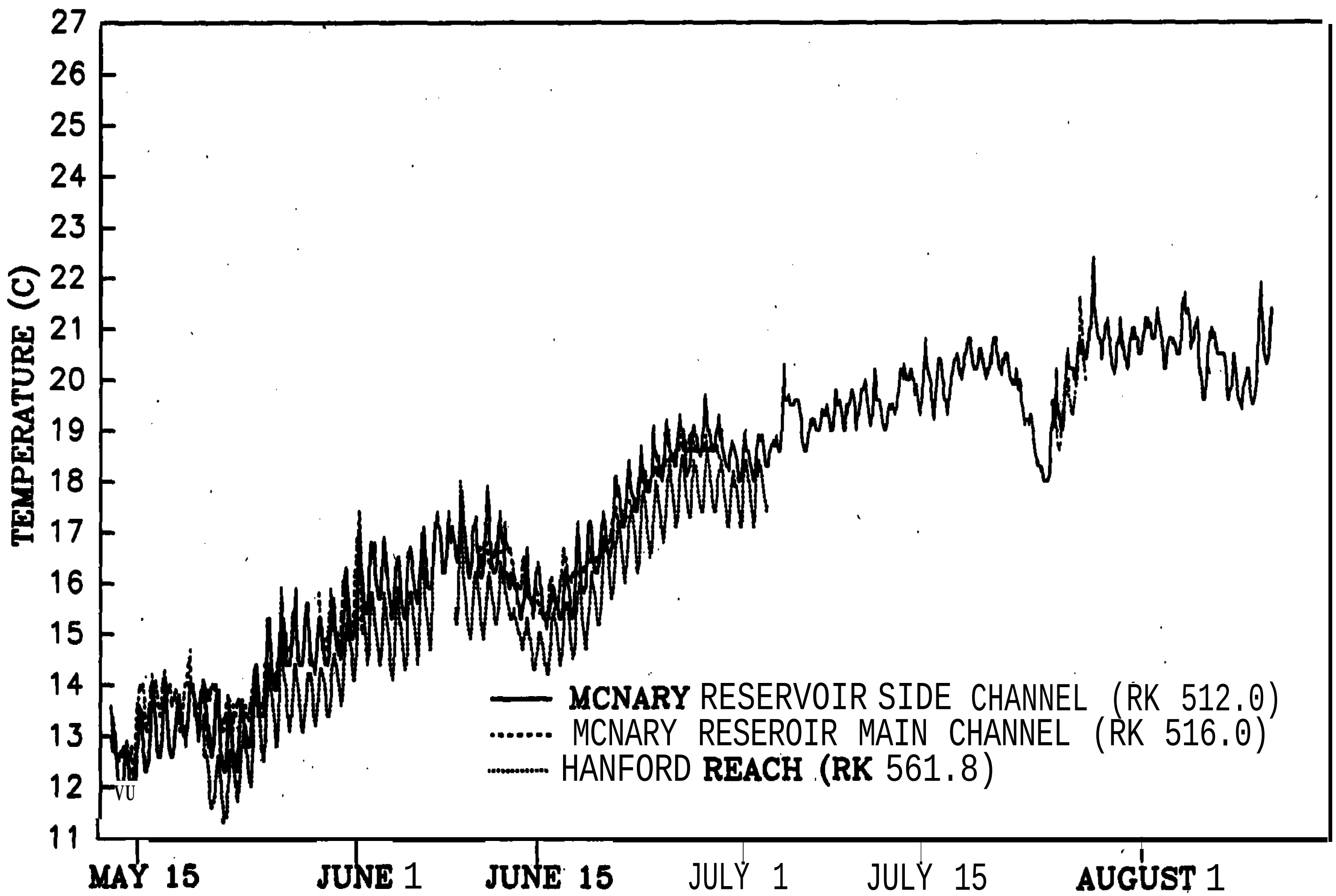

Figure 9.—Hourly temperature fluctuations measured by thermographs in nearshore areas of McNary Reservoir and the Hanford Reach, Columbia River, Washington 1992.

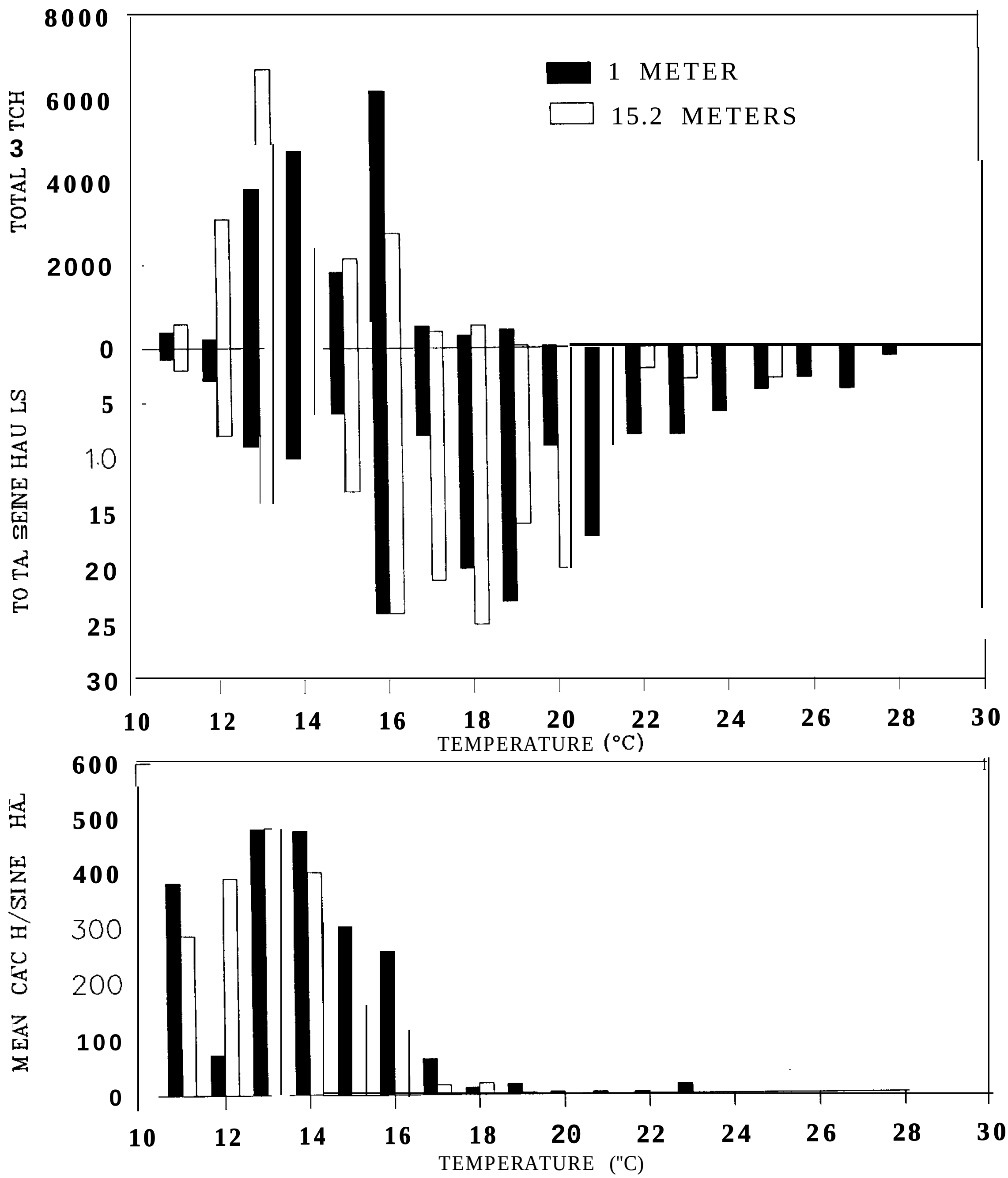

Figure 10.—Total catch, total seine hauls, and mean catch/seine haul of subyearling chinook salmon. Temperature was measured at 1 m and 15.2 m from the shoreline in McNary Reservoir of the Columbia River, Washington.

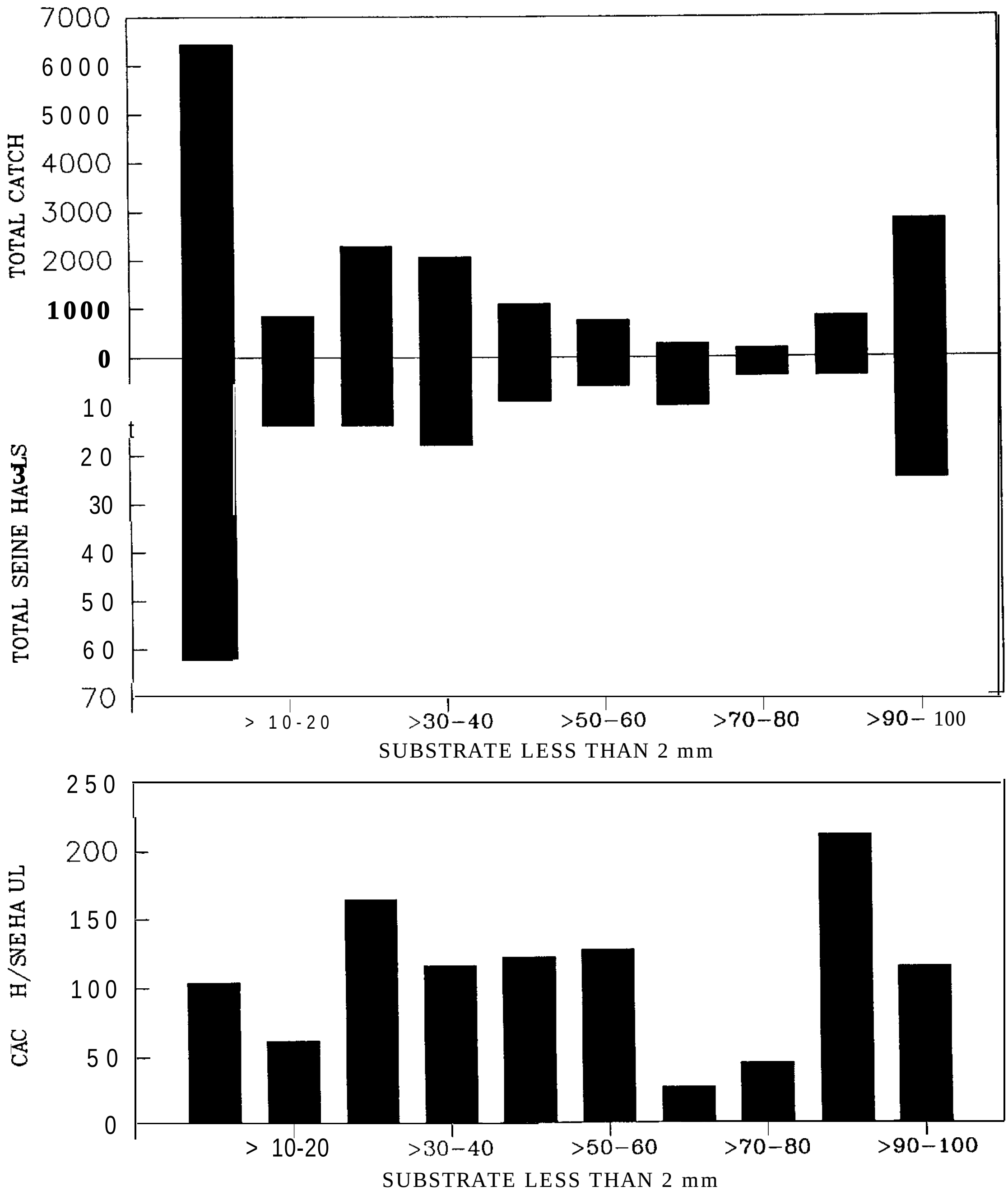

Figure 11.— Total catch, total seine hauls, and mean catch/seine haul of subyearling chinook salmon in McNary Reservoir of the Columbia River, Washington. The percent area of the beach seine site was determined for each seine haul where dominant substrate was fines <2 mm in size. Areas were combined into 10% intervals and graphed.

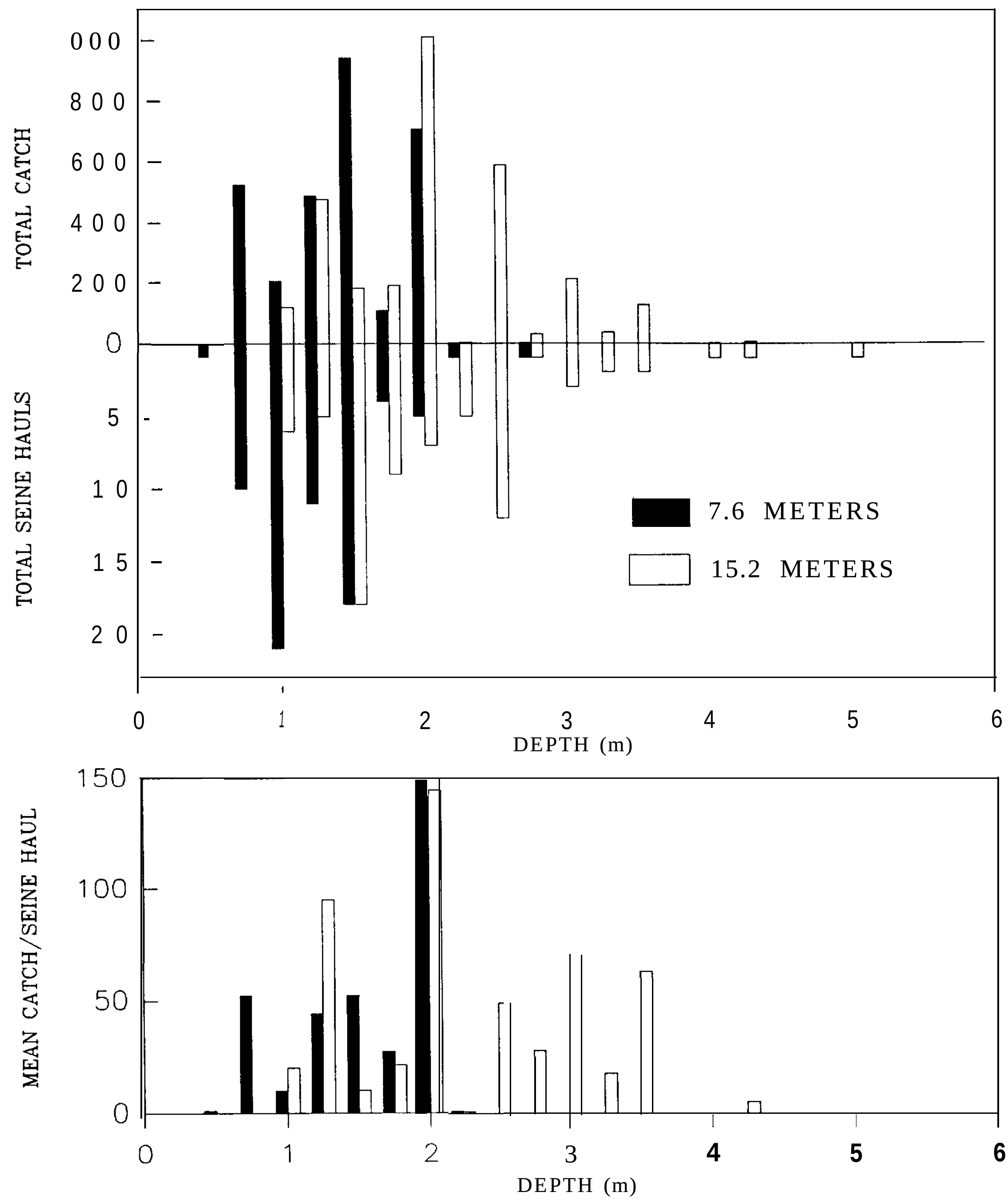

Figure 12.-Total catch, total seine hauls and mean catch/seine haul of subyearling chinook salmon. Depth was measured at 7.6 m and 15.2 m from the shoreline in the Hanford Reach of the Columbia River, Washington.

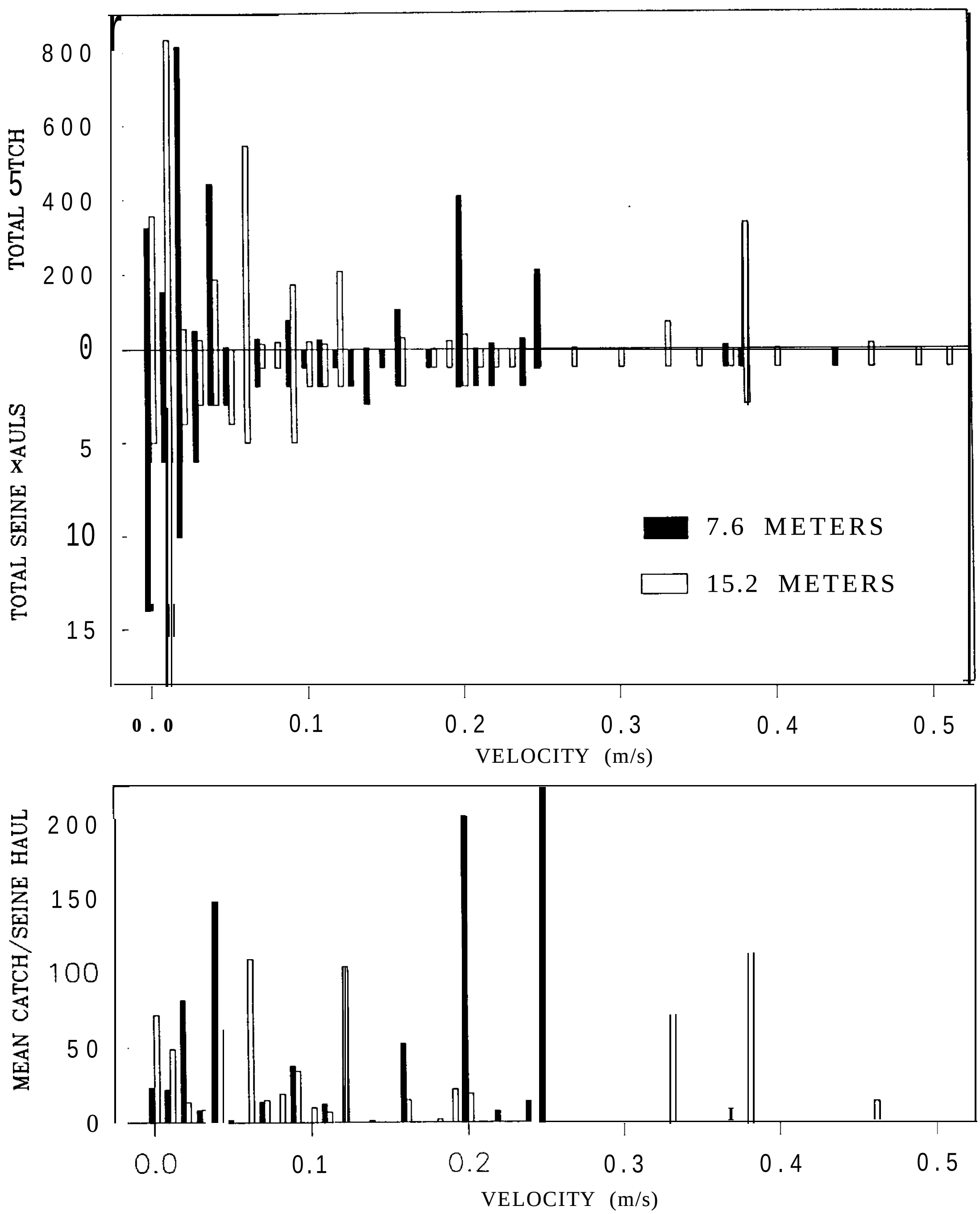

Figure 13.— Total catch, total seine hauls, and mean catch/seine haul of subyearling chinook salmon. Velocity was measured at 7.6 m and 15.2 m from the shoreline in the Hanford Reach of the Columbia River, Washington.

thermograph in a nearshore area had a range of 1.5°C and were approximately a degree cooler than those from McNary Reservoir (Figure 9). Effort was highest for sites where water temperature was between 14.0-18.9°C at both 1 m and 15.2 m from shore (Figure 14). Highest mean catch per seine haul occurred at temperatures between 14.0-15.9°C at 1 m and 13.0-13.9°C at 15.2 m from shore. Subyearling chinook salmon were not caught where temperature exceeded 21.2°C at 1 m from shore but were caught over the entire temperature range (12-19.9°C) measured 15.2 m from shore. Most subyearling chinook salmon were caught in sites that contained a low percent of substrate <2 mm (Figure 15).

In the Snake River, seining effort was highest between 0.76 m and 1.25 m depth at 7.6 m from shore and between 1.76-2.75 m at 15.2 m from shore, with no apparent trends in average catch per seine haul (Figure 16). Effort was highest for velocities <0.05 m/s but the mean catch per seine haul was relatively high when velocities were between 0.3-0.4 m/s (Figure 17). Effort was highest for sites where water temperature was between 13.0-17.9°C at 1 m and between 12.0-17.9°C at 15.2 m from shore (Figure 18). Highest mean catch per seine haul occurred at temperatures between 13.0-15.9°C at 1 m and 13.0-13.9°C at 15.2 m from the shore. No subyearlings were caught when temperatures exceeded 20.4°C at 1 m from shore or 19.2°C at 15.2 m from shore.

Discussion

The McNary Reservoir population of subyearling chinook salmon is primarily derived from fish naturally spawning in the Hanford Reach and releases from Priest Rapids State Fish Hatchery. Emergence of fry from redds in the Hanford Reach began 32 days earlier in 1992 than in 1991 (Carlson and Dell 1992). Because of the earlier emergence, beach seining activities did not include the early rearing period of subyearlings in nearshore areas. Snake River collections were made during and following emergence until few subyearlings could be collected in the nearshore areas.

The mean fork length of subyearling chinook salmon remained lower in the Hanford Reach than in McNary Reservoir. The time required for subyearling chinook salmon to disperse 38 km from the downstream-most sampling point in the Hanford Reach to the upstream-most sampling point in McNary Reservoir may explain their consistently larger mean fork length in McNary Reservoir.

The greater mean fork length of subyearling chinook salmon in the Snake River may be a result of warmer water temperature. Emergence of fry from redds in the Hanford Reach was reported to occur between 20 February and 21 April 1992 (Carlson and Dell 1992) and in the Snake River between 18 March and 25 May (Connor et al. this report). Since subyearlings emerged later but were larger in the Snake River than in the Hanford Reach, they

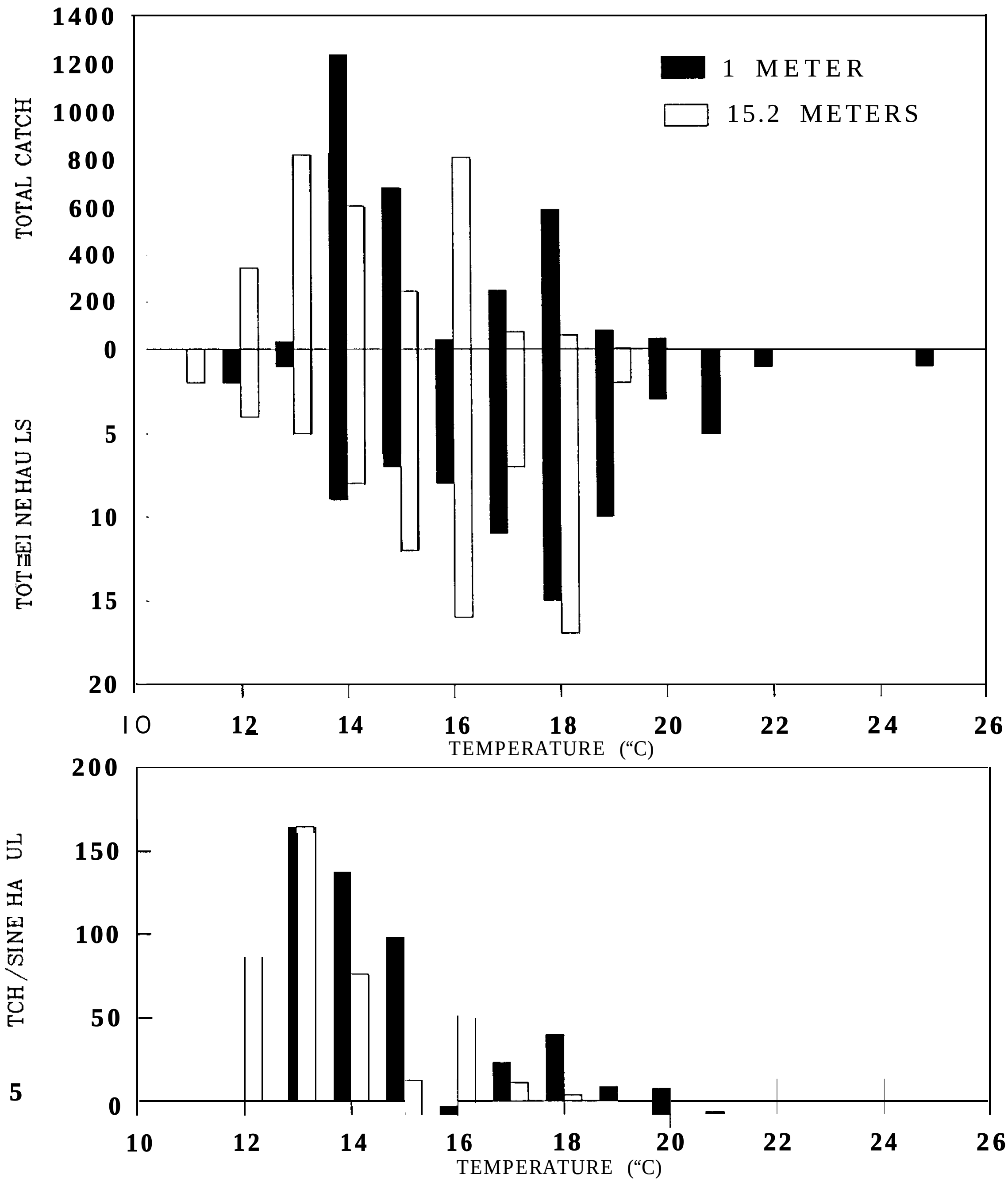

Figure 14.—Total catch, total seine hauls, and mean catch/seine haul of subyearling chinook salmon. Temperature was measured at 1 m and 15.2 m from the shoreline in the Hanford Reach of the Columbia River, Washington.

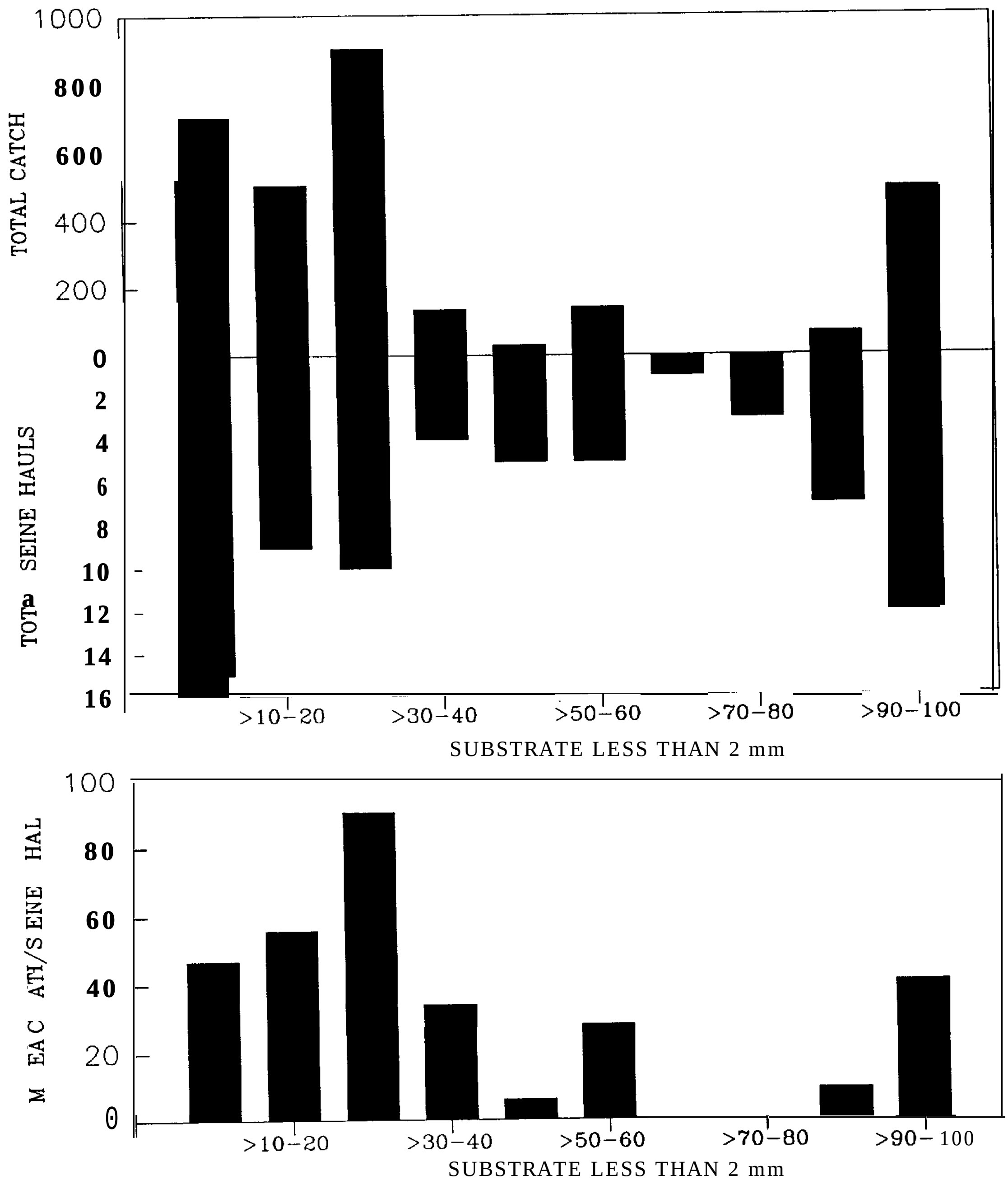

Figure 15.—Total catch, total seine hauls, **and mean catch/seine haul of subyearling chinook salmon in the Hanford Reach of the Columbia River, Washington. The percent area of the beach seine site was determined for each seine haul where dominant substrate was fines <2 mm in size. Areas were combined into 10% intervals and graphed.**

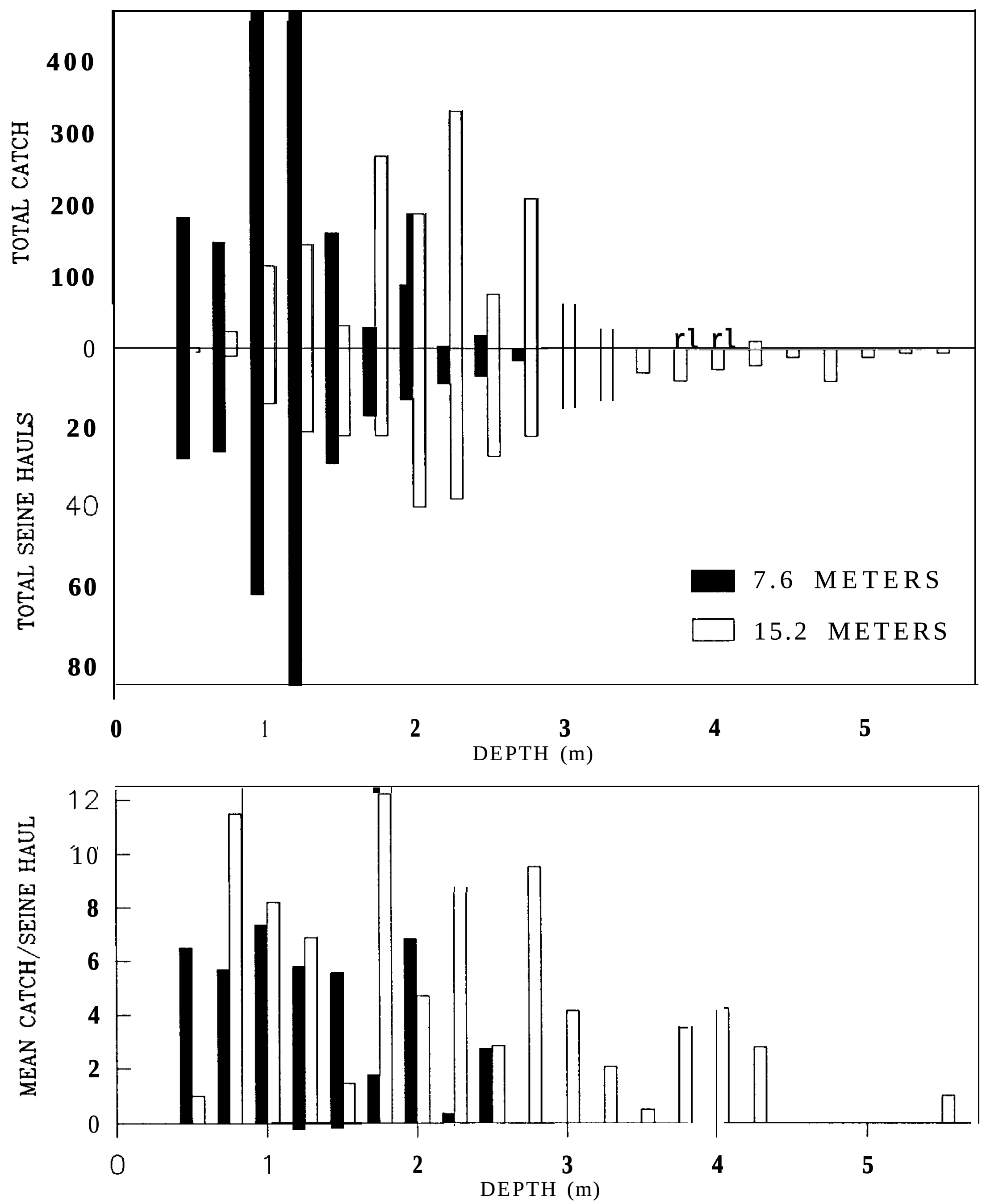

Figure 16.— Total catch, total seine hauls, and mean catch/seine haul of subyearling chinook salmon. Depth was measured at 7.6 m and 15.2 m from the shoreline in the Snake River, Idaho, Oregon, and Washington.

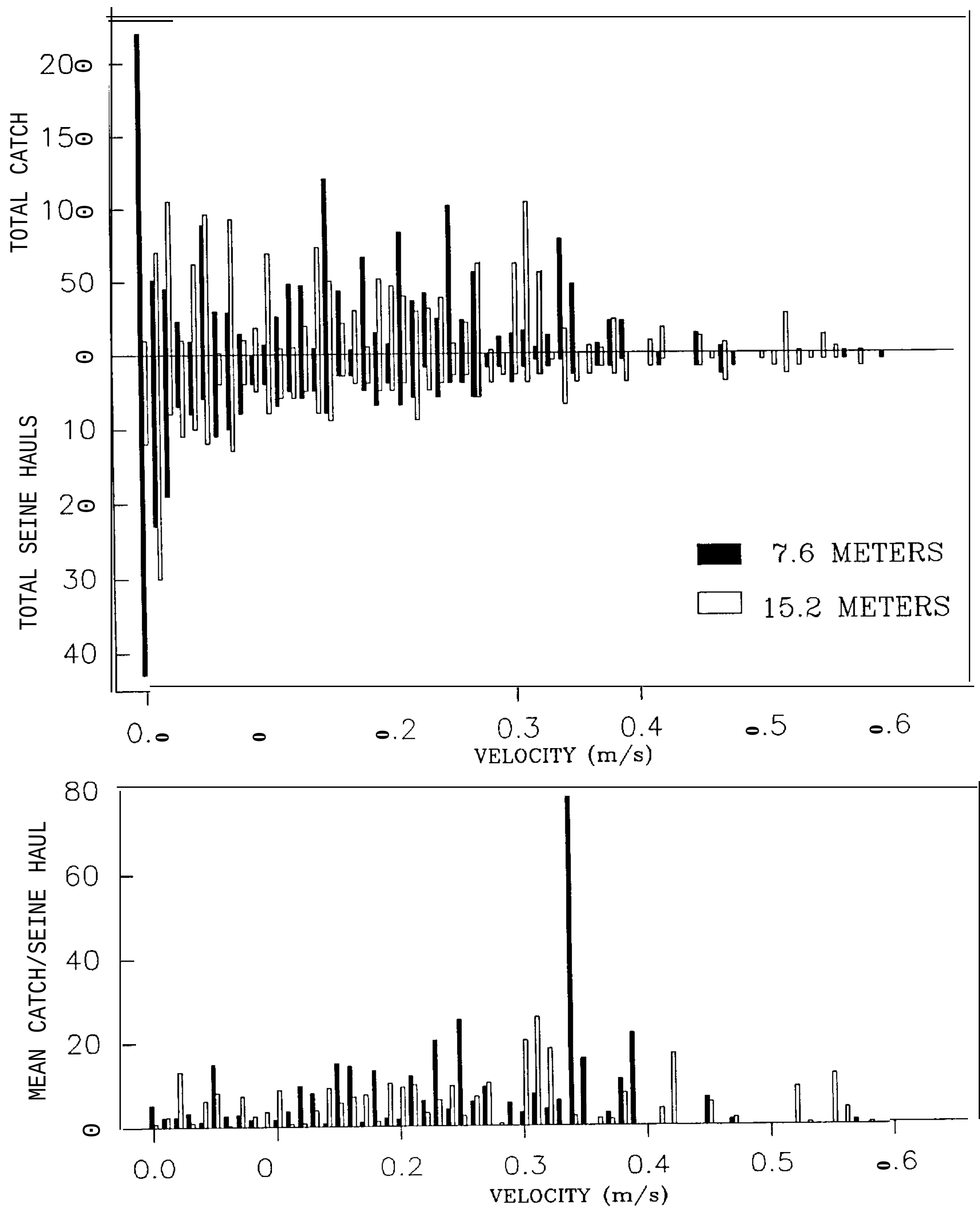

Figure 17.—Total catch, total seine hauls, and mean catch/seine haul of subyearling chinook salmon. Velocity was measured at 7.6 m and 15.2 m from the shoreline in the Snake River, Idaho, Oregon, and Washington.

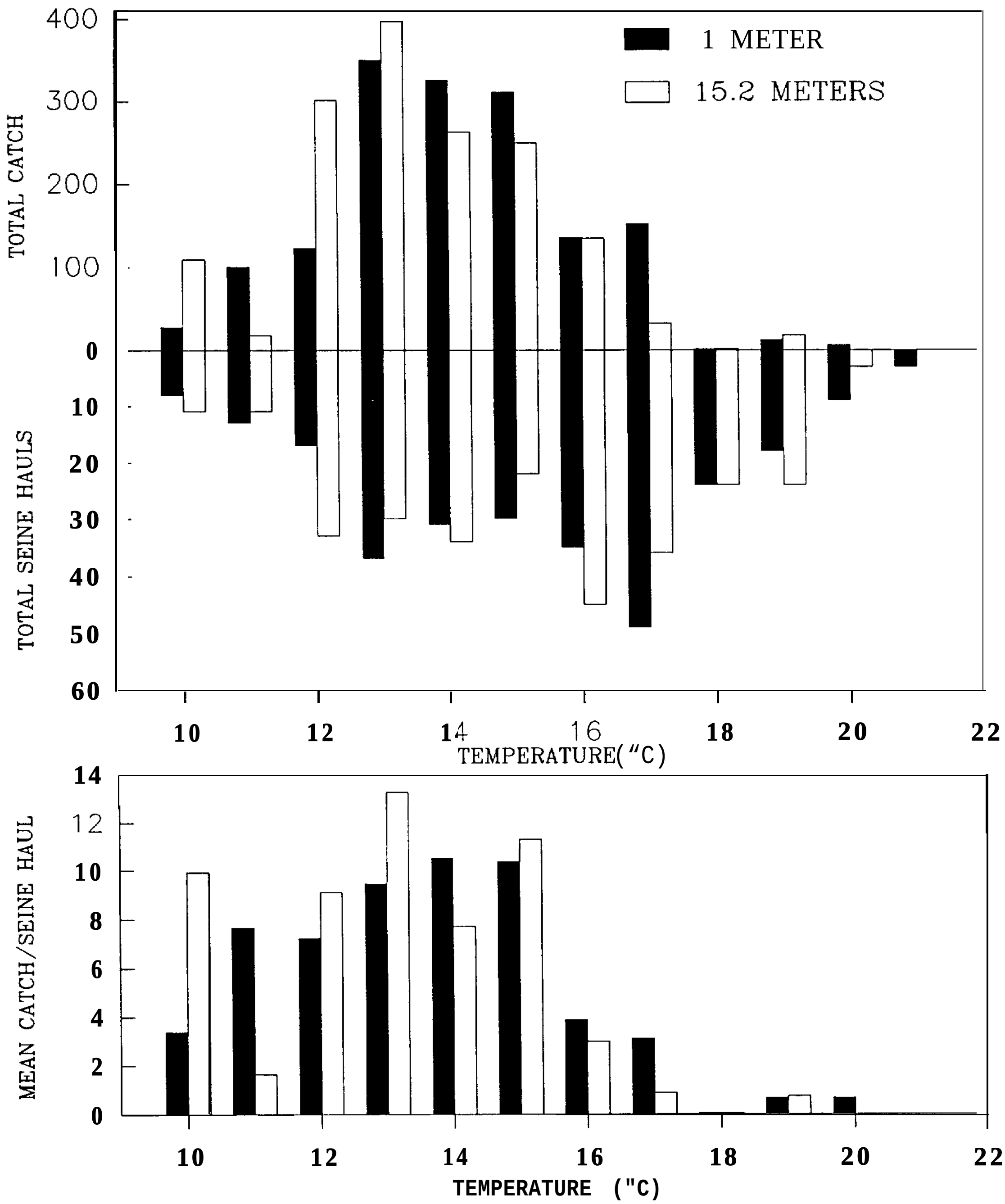

Figure 18.—Total catch, total seine hauls, and mean catch/seine haul of subyearling chinook salmon. Temperature was measured at 1 m and 15.2 m from the shoreline in the Snake River, Idaho, Oregon, and Washington.

achieved considerably faster growth upon emergence. Fall chinook salmon fry emerged in the Hanford Reach when daily mean water temperatures were between 5°C and 9°C (Carlson and Dell 1992) but in the Snake River they emerged when water temperatures were between 7.4°C and 14.9°C (Connor et al. this report). In a laboratory, as water temperature was increased feeding and growth of alevins began earlier (Heming et al. 1982). Subyearling chinook salmon in the Hanford Reach had the lowest feeding intensity in March and April when temperature ranged from 3°C to 8°C (Becker 1973). Subyearlings emerging in the water of the Hanford Reach may not grow as quickly as fish emerging in the relatively warmer Snake River. In addition to temperature, stock differences could have contributed to observed differences in length. Longer emigration distance from the Snake River than from the Hanford Reach may have selected for fish able to attain a larger size at emigration (Taylor 1990). Statistical analysis and collection of additional information should reveal whether subyearling chinook salmon attain larger size more quickly in the Snake River than in the Columbia River.

Although Snake River subyearling chinook salmon may increase in length more quickly, they appear to increase in weight in the same proportion to length as subyearlings in the Hanford Reach. The differences in the length-weight curve for fish in McNary Reservoir (Figure 4) could simply be a result of hatchery fish released into the Columbia River. Over seven million hatchery subyearlings were released below Priest Rapids Dam between 12 and 24 June 1992 (Fish Passage Center 1993). Following 12 June large numbers of subyearlings of larger size, greater weight, and less fusiform appearance were observed in the McNary Reservoir catch. The greater weight may have shifted the slope of the curve to the left for fish captured in McNary Reservoir compared to the riverine reaches.

The catch of subyearling chinook salmon was positively correlated with light and was significantly higher during the day than at night. The higher daytime catch in this study agrees with the findings of previous studies conducted with a beach seine in the Columbia River Estuary (Ledgerwood et al. 1991). Catch of subyearlings with a purse seine was also higher during the day than at night in the estuary (Ledgerwood et al. 1991) and in John Day Reservoir on the Columbia River (Sims et al. 1976). These studies suggested that chinook were moving deeper into the water column beyond the reach of the seines at night. Underwater observation studies have shown that preceeding darkness small diurnal schools of fish disbanded, moved to the bottom, and spaced themselves out on, or just above, the substrate (Emery 1973; Helfman 1981). This behavior was explained as a mechanism to avoid nocturnally active predators. Although it is generally accepted that net avoidance is greatest during the day, fish that become torpid at night may not be caught if the leadline skims over the top of them or if they are in water deeper than the reach of the net. If subyearlings are actively using nearshore areas during the day to move and feed, then daytime would be the most appropriate time to study movement patterns and active use of depth, velocity, substrate, and vegetation.

Shallow nearshore water depth may be important to subyearling chinook salmon by providing an environment with warmer water temperatures and lower risk of predation from large piscivorous fish. Bennett et al. (1993) found that subyearling chinook salmon in Lower Granite Reservoir were caught most frequently at low gradient sites. However, our findings suggest that there may be a minimum slope that subyearling chinook salmon will inhabit. Extremely shallow water may place small fish at a higher risk to avian predation by reducing escapement into deeper water depths; avian predation was observed daily by workers in the field during daylight hours. In addition, sites with very low slope dewater rapidly as reservoir and river levels fluctuate daily, and sometimes hourly, and may cause stranding.

As juvenile salmon grow they tend to shift to higher velocities and deeper water (Lister and Genoe 1970; Hillman et al. 1987). Personal observations in the field support these findings. Subyearlings were observed to feed at increasing distances from the shoreline as the season progressed and mean length increased. In late June, when beach seine hauls captured few subyearling chinook salmon, fish were observed feeding beyond the range of the beach seine. These observations suggest that the lack of a relationship between velocity and catch may be an artifact of grouping catches and velocity intervals across the entire sampling season and further study and analysis are required before a definitive conclusion can be reached.

Temperature avoidance may affect movement from nearshore areas. Mean catch dropped when temperatures exceeded 15.9°C. In all three reaches the mean catch peaked when temperatures were between 12.0-15.9°C. However, because river temperature and subyearling chinook salmon length both increase with time, it is difficult to separate temperature factors from the physical and physiological changes in subyearling chinook salmon that can affect behavior.

Substrate is commonly reported as an important component of the habitat for resident fish in streams and small rivers where it may provide protection from high velocity or predators. In the Snake River, Bennett et al. (1993) reported that of the total subyearling chinook salmon caught, 72% were captured over substrates consisting of >75% fines, however, effort was not reported. Catch of subyearling chinook salmon appeared to be proportional to effort over a range of percent fine substrate in the Hanford Reach and McNary Reservoir. High effort resulted in high total catch of subyearlings in McNary Reservoir and Hanford Reach. Since catch appeared dependent on effort, a conclusion regarding association of subyearling chinook salmon with substrate could not be supported, We propose that subyearling chinook salmon are generalistic feeders consuming prey items from the water column and the surface (Becker 1973; Rondorf et al. 1990) and moving freely in the water column as loose aggregates (personal observation). A snorkel study in the Sixes River, Oregon observed subyearling fall chinook salmon inhabiting backwater eddies near shore, distributed throughout the water column and consuming prey from the drift (Stein et al. 1972). This nondemersal behavior of subyearlings during the day could explain a lack of association between substrate and catch and the proportional relationship between effort and catch.

In conclusion, peak numbers of subyearling chinook salmon were captured during May in all reaches but as water temperatures increased above 15.9°C, mean catch decreased. The Snake River subyearling chinook salmon emerged later and attained a larger size more quickly than the Columbia River subyearlings. Subyearlings were caught in significantly greater numbers during the day than during the night. Most subyearlings were caught in water between 0.5 m and 2.0 m deep. Substrate did not appear to have an influence on catch of subyearling chinook salmon in the main-stem Columbia River. Habitat shifts by fall chinook salmon may occur in the nearshore areas but that analysis has been deferred with only one year of data available.

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CHAPTER SEVEN

Distribution of Juvenile Chinook Salmon and American Shad in McNary and John Day Reservoirs

by

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Introduction

Considerable research has been conducted to determine the influence of flow on the rate of juvenile chinook salmon *Oncorhynchus tshawytscha* outmigration in the Columbia River (Raymond 1969; Sims et al. 1981; Faurot et al. 1982; Miller and Sims 1983, 1984). Smolt travel time comparisons have been made between pre- and post-impoundment (Raymond 1969, 1988), and early and late migrants (Giorgi 1991), but there is still little agreement as to the importance of flow in regards to juvenile chinook salmon migration (Giorgi 1991; Berggren and Filardo 1993). Part of the difficulty stems from the inability to study any single environmental factor versus fish migration rate. Various authors have proposed smoltification, flow, time of year, water temperature, turbidity, and lunar phase as important in determining rate or readiness to migrate seaward. Furthermore, juvenile salmon movement and distribution within reservoir environments remains poorly understood.

Several investigators correlated fish movement in John Day Reservoir with flow using radio telemetry data (Sims et al. 1981; Faurot et al. 1982; Miller and Sims 1983, 1984). Incidental hydroacoustic data were gathered on juvenile salmonid distribution during a study of predator distributions in Lower Granite Reservoir (Thorne et al. 1992). Still there is **a** need to determine the distribution of juvenile salmon in the main stem reservoirs of the Columbia and Snake rivers to better understand how changes in water flow affect their migration.

The objective of this study **was** to determine if distribution of subyearling chinook salmon in main stem reservoirs explains the relatively slow downstream migration during summer. This study seeks to define the role of water velocity and other environmental variables in determining the distribution of subyearling chinook salmon in the cross sections of reservoirs. The first year of work reported here was used to develop an integrated sampling system and gather preliminary data to determine the best sampling protocols and analytical approaches.

Methods

Hydroacoustics and trawl surveys were conducted on McNary and John Day reservoirs during the summer of 1992. McNary Reservoir surveys were conducted from 7 July to 16 July and John Day Reservoir was sampled 22 July to 7 October. These reservoirs were selected because of the large number of subyearling fall chinook salmon that are naturally produced in the Hanford Reach or released from hatcheries upriver.

McNary Reservoir was divided into reaches for hydroacoustic surveys. Three reaches were selected for sampling, each 6 km long, based on potential diversity between hydrologic cross-sections. Reach 1 (river kilometer (RK) 476 to RK 483), located 8 km above McNary Dam had the deepest water and lowest water velocities. Reach 2 (RK 497 to RK 502) was of intermediate depth and water velocity. Reach 3 (RK 512 to RK 518), 16 km below the confluence of the Snake and Columbia rivers had the shallowest water and highest water velocities. In John Day Reservoir three reaches were also surveyed, but only data from reach 2, RK 385 to RK 391, are reported here.

Within each reach, four transects were randomly selected within each 1.5 km of river. Transects were set up perpendicular to the shore. This design allowed random selection of starting transects and was a compromise between total random sampling which would have been inefficient and systematic sampling which could introduce the greatest bias into the samples. Transects were sampled beginning at the most down-river transect and proceeded sequentially upstream so that fish detected in one transect would not likely be detected in the next transect, thereby reducing potential covariance among transects.

The hydroacoustic survey vessel was equipped with a dual beam echosounder for detecting fish in the water column, an acoustic doppler current profiler (ADCP) for measuring water column velocities, and **a** midwater trawl for capturing fish. During each transect the echosounder recorded echo intensity of fish in the water column, while the ADCP simultaneously recorded velocity profiles. By using a dual beam echosounder system the relative size of fish could be determined from the recorded information. A global positioning system (GPS), which fixes latitude and longitude, was used to locate and navigate transects. The latitude and longitude information was linked to the echosounder data so fish locations could be mapped.

A midwater trawl made of monofilament mesh was used to collect data on fish size and species composition in pelagic areas of the reservoir. These data were used to verify size estimates and target strengths from hydroacoustic surveys. Fish concentrations were identified during hydroacoustic surveys and trawl samples were collected in areas of highest concentration after all hydroacoustic transects within a river kilometer had been completed. The trawl was deployed for five minutes at a designated sampling depth. Fish were identified to species, measured, and released.

ADCP data were collected in an unprocessed form in 0.5 meter depth intervals. The ADCP uses 600 KHz frequency pings to ensonify small particles in the water such as silt, plankton, and organic debris. An ensemble of pings is generated and the Doppler shift is measured from the echoes off particles within each depth interval. Particle velocities are estimated from the magnitude of shift in frequency of echoes, and north, east, and vertical velocity vectors are subsequently generated. The velocity vectors are then combined to generate a velocity magnitude for each depth interval within an ensemble. Each unprocessed ensemble takes four to five seconds to complete. After comparing the results of averaging raw data ensembles for 10 s, 20 s, and 30 s periods, in 0.5 m and 1 m depth intervals, unprocessed data for individual ensembles were combined and averaged over 30 s (30 m to 40 m depending on vessel speed) in 1 m depth intervals to assist in data analysis.

Relative fish size was determined by the target strength of echoes processed by the dual beam echosounder. An echo received from a single source is referred to as a target. Target strength is the echo intensity of ensonified objects in the water column. A grouping of targets that matches user defined criteria is classified as a fish and will have an average target strength from which fish size can be estimated. Fish located by the echosounder were matched to velocities measured by the ADCP using elapsed time and depth. This is based on trawl catch data and recorded average target strengths from -58 decibels (db) to -46 db which is the range expected for fish less than 200 mm. Records of gas bubbles were identified by clustered and vertically rising patterns and were deleted.

The volume of water sampled by the echosounder was calculated for each 0.5 m depth interval generated by the ADCP using the estimated width of the echosounder beam at mid-depth of the velocity cell. Fish density per 10,000 m^3 of water was computed for each group of transects based on the total volume of water sampled (ensonified) and the number of fish ensonified (N), taking into account the inverted cone shape of the echosounder beam (i.e., a greater volume was sampled at greater depth).

Data from hydroacoustic transects were grouped for analysis by time and location into eight groups. The frequency of velocities and depth which fish were located were compared to an expected random distribution using a Kolmogorov-Smirnov Goodness of Fit test (Zar 1984). The frequency of velocities and depths which fish were located were also compared to the frequency of those variables in reservoir cross sections sampled. The number of fish was adjusted for ensonified volume sampled by the echosounder. Because of the preliminary nature of this report, the density estimates do not include an estimate of variability. Median values of water velocity in cross sections, depth in cross sections, and velocity and depths where adjusted numbers of fish were located were calculated as measures of central tendency and tested using the median test (Zar 1984).

Results

Species composition

Juvenile chinook salmon made up 99% of the trawl catch in McNary Reservoir surveys (Table 1). Average fork length of juvenile chinook salmon captured in trawl samples was 110 mm (range 91 mm to 150 mm). The number of juvenile chinook salmon caught in trawl samples had diminished by 16 July at which time McNary Dam juvenile chinook salmon passage indices were also rapidly declining (Figure 1). We assumed that most fish with target strengths from -58 db to -46 db detected in McNary Reservoir during July were subyearling chinook salmon based on the trawl catches, target strengths, and juvenile salmon fish passage information at McNary Dam.

Juvenile American shad *Alosa sapidissima* made up 99% of the trawl catch in John Day Reservoir where sampling began on 22 July. Average fork length of American shad captured in trawl samples was 66 mm (range 35 mm to 116 mm). Juvenile chinook salmon and other species made up less than 1% of trawl catch in John Day Reservoir (Table 1).

Juvenile chinook salmon distribution

Fish density during night sampling in July was about twice that observed during the daytime sampling. Fish density during night samples ranged from 22-39 fish/IO,000 m^3 water for transects that began at 2045-2305 hours (Table 2). Density observed during the day ranged from 7-16 fish/10,000 m^3 water for transects that began at 1248-1955 hours.

Fish located by echosounder were distributed randomly across the range of water velocities available in one of four groups of transects. In three groups of transects starting between 1248 and 2310 hours, the frequency distribution of water velocities selected by fish was significantly different from random (P c 0.05; Table 3). In a fourth group of transects in which sampling started at 2224 and 2305 hours, the frequency of water velocities selected by fish was randomly distributed ($P > 0.05$; Table 3).

The frequency of water velocities selected by fish did not reflect the frequency of water velocities available in reservoir cross sections. The water velocities measured by the ADCP were considered representative of those available in the reservoir cross sections and are presented as one meter deep cells with an average velocity for that cell (Figure 2). The availability (number of cells) in the reservoir cross section with a specific water velocity is indicated by the open bars of the histograms in Figure 3 (Availability). The estimated density of fish at specific water velocities is shown by the black bars on the lower half of each plate (Usage; Figure 3). The frequency of water

Table 1.— Species composition and catch for trawl surveys conducted in McNary and John Day reservoirs, 1992.

Date	Time	Species[1]	Avg FL	Total	Percent Catch	River (km)
		McNary Reservoir				
7-07-92	1636	CHN	106	59	100	481
7-07-92	1733	CHN	105	91	100	500
7-14-92	1357	CHN	115	8	89	486
7-14-92	1425	CHN	114	30	100	484
7-14-92	1425	CRP	NA	1	11	484
7-15-92	2034	CHN	105	3	100	497
7-15-92	2247	CHN	122	10	100	499
7-16-92	1928	CHN	115	1	50	502
7-16-92	1928	SOC	121	1	50	502
		John Day Reservoir				
7-22-92	1313	CHN	121	1	100	417
7-24-92	1312	NA	NA	0	NA	360
7-24-92	1345	NA	NA	0	NA	360
7-29-92	2115	NA	NA	0	NA	386
7-30-92	2219	ASH	44	217	100	387
7-31-92	1549	CHN	90	2	100	386
8-13-92	1722	ASH	58	18	100	387
8-31-92	1905	ASH	67	42	100	389
g-01-92	1131	ASH	74	13	100	386
g-01-92	1319	ASH	80	30	91	387
g-01-92	1319	CRP	NA	3	9	387
g-01-92	1457	ASH	80	10	100	389
g-02-92	2204	CHN	64	1	2	386
g-02-92	2204	ASH	54	50	98	386
g-02-92	2354	CHN	110	3	7	387
g-02-92	2354	ASH	57	40	93	387
10-05-92	1451	CHC	62	1	3	386
10-05-92	1451	ASH	82	31	97	386
10-06-92	1204	ASH	71	42	100	386
10-06-92	1344	ASH	67	38	100	387
10-06-92	1511	ASH	70	9	100	389
10-07-92	1956	ASH	78	8	100	386
10-07-92	2123	ASH	68	5	100	387
10-07-92	2302	ASH	76	23	100	389

'Species abbreviations are ASH; American shad *Alosa supidissima*, CHC; channel catfish *Ictulurus punctatus*, CHN; chinook salmon *O. tshawytscha*, CRP; common carp *Cyprinus carpio*, and SOC; sockeye salmon *O. nerka*.

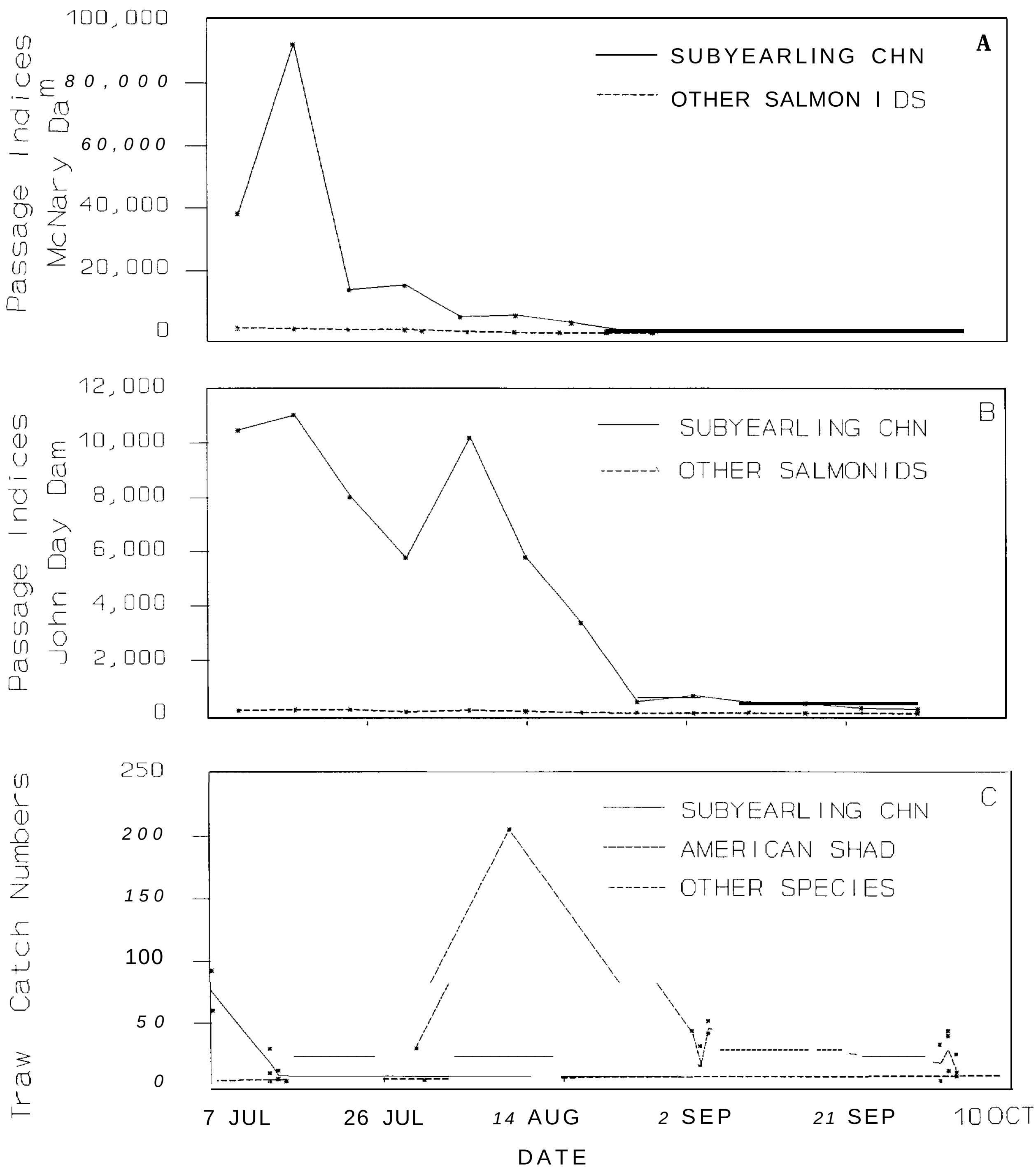

Figure 1.(A)-Daily passage indices of juvenile salmonids at McNary Dam (averaged and plotted weekly), from 7 July through 10 October 1992. (B) Daily passage indices of juvenile salmonids at John Day Dam (averaged and plotted weekly), from 7 July through 10 October 1992. (C) Trawl catch data from McNary and John Day reservoirs from 7 July through 10 October 1992. Each symbol represents a single trawl catch for that species or group.

Table 2.-Representative hydroacoustic results for transects surveyed in McNary Reservoir 7 July to 16 July and in John Day Reservoir 22 July to 7 October 1992.

Group	River Kilometer	Date	Time	Number of Fish	Fish Density[1]
1	512	7-11-92	1248	7	11
	513	7-11-92	1314	8	15
2	500	7-8-92	1900	14	13
	500	7-8-92	1932	8	7
	500	7-8-92	1955	17	16
3	512	7-12-92	2045	16	22
	518	7-12-92	2247	13	30
	518	7-12-92	2310	6	22
4	497	7-9-92	2224	43	32
	499	7-9-92	2305	47	39
5	387	9-l-92	1200	31	12
	387	9-l-92	1227	8	3
	387	9-l-92	1245	19	8
6	389	8-31-92	1752	30	13
	389	8-31-92	1815	40	18
	389	8-31-92	1836	23	11
7	386	9-2-92	2042	61	22
	386	9-2-92	2103	94	32
	386	9-2-92	2127	86	29
8	389	9-3-92	0020	176	71
	389	9-3-92	0107	278	121

'Fish density reported as fish/10,000 m^3.

Table 3.-Results from Kolmogorov-Smirnov test of goodness of fit for subyearling chinook salmon and American shad based on availability and usage associated with velocity and depth in hydroacoustic transects in McNary and John Day reservoirs. Symbols: * = $P < 0.05$; ** = $P < 0.01$; NS = no significant difference.

				Velocity		Depth	
Group	Date	Start time	N	Range Sampled	Cells Available	Range Sampled	Cells Available
				Subyearling Chinook salmon			
1	7-11-92	1248	15	**	**	NS	NS
2	7-08-92	1900	39	*	**	**	**
3	7-12-92	2045	35	**	**	NS	NS
4	7-09-92	2224	90	NS	**	**	**
				American shad			
5	g-01-92	1200	58	**	**	NS	**
6	8-31-92	1752	93	NS	**	NS	**
7	g-02-92	2042	241	**	**	*	**
8	g-03-92	0020	454	**	**	**	**

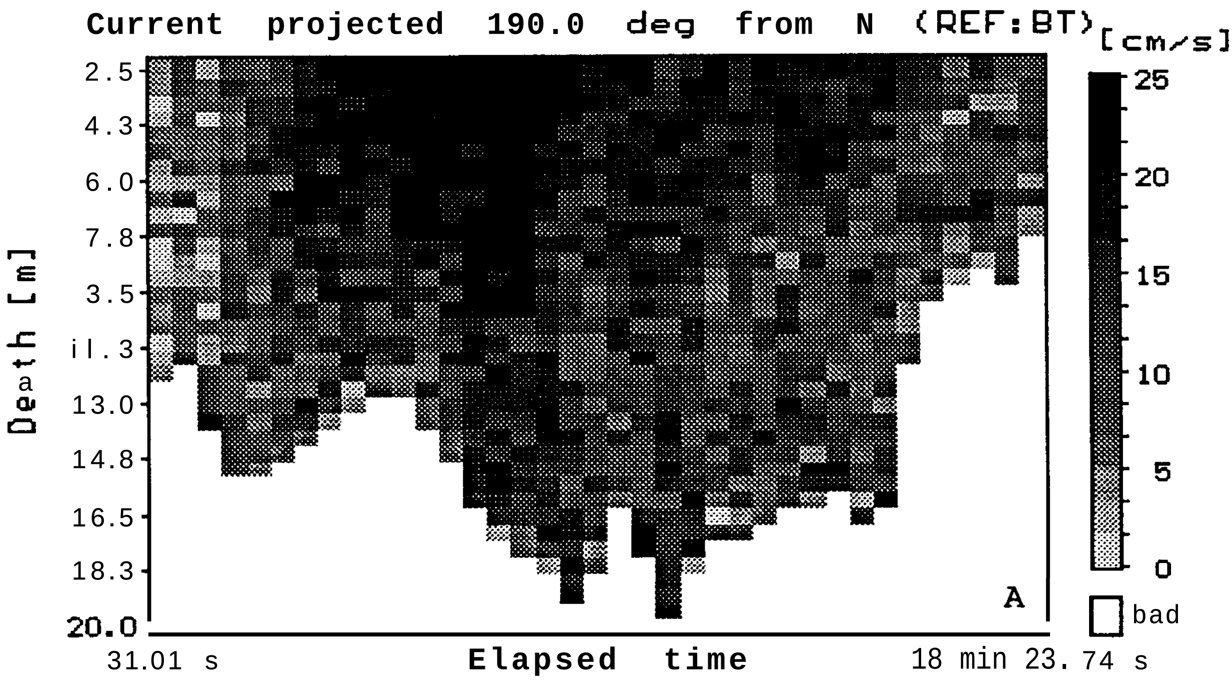

Figure 2.— Example of ADCP velocity profile for a reservoir cross section surveyed at river km 500, 8 July 1992. Data were averaged every 30 s in 1 m depth intervals.

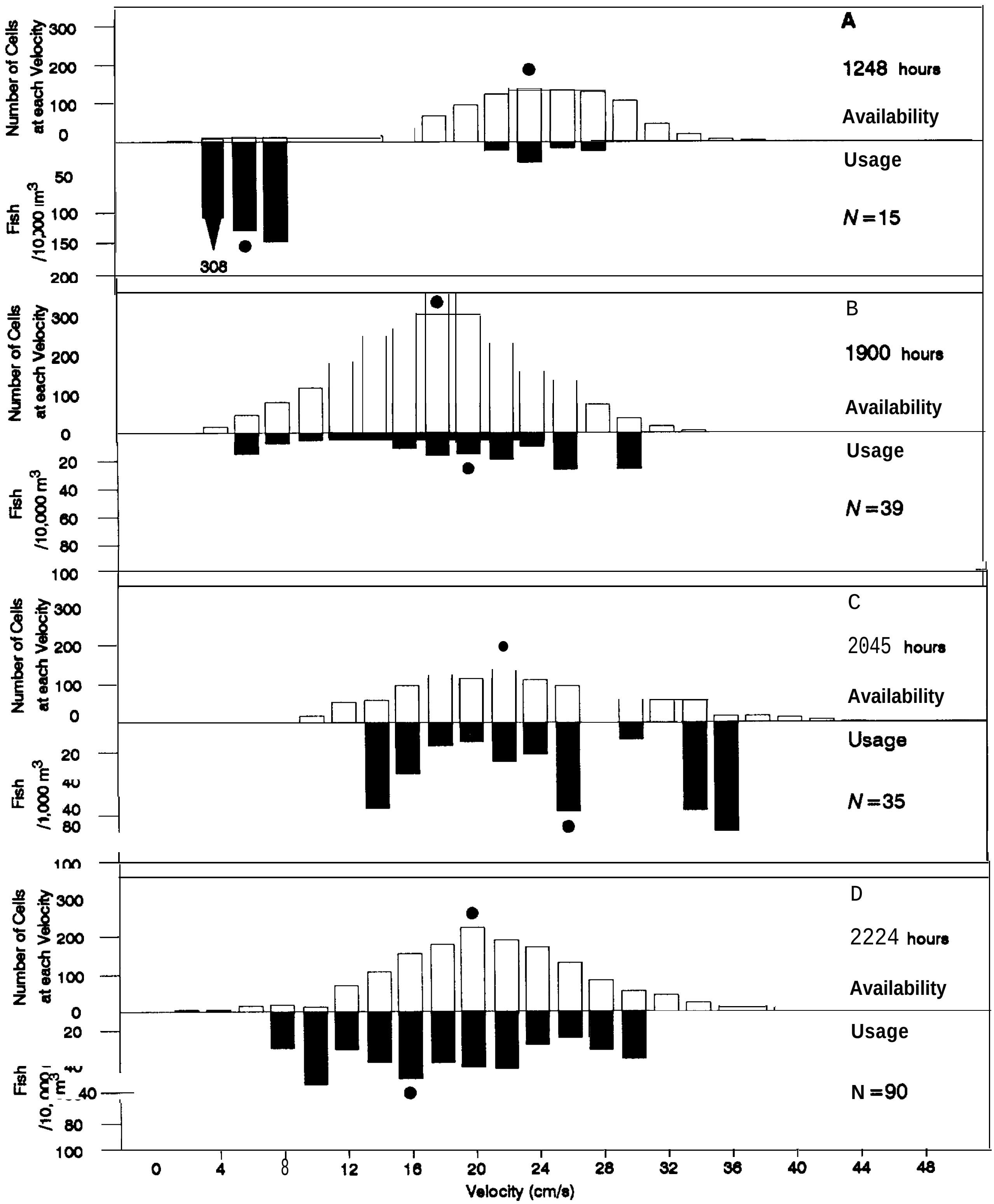

Figure 3.— Frequency histograms of available velocity cells and associated fish density by velocity for hydroacoustic surveys performed in McNary Reservoir, 1992. Medians are denoted as (●).

velocities available and the water velocities selected by fish were significantly different (P c 0.01; Table 3). Fish detected in transects starting at 1248 and 1314 hours were mostly distributed in waters with velocities < 8 cm/s (Figure 3A), whereas fish detected during night transects starting at 2045-2305 hours were associated with velocities ranging from 8 cm/s to 36 cm/s (Figure 3B,C,D).

The depth selected by fish during day and night may have been associated with the morphology of the cross sections. The depths fish selected in transects sampled starting at x248-1314 hours and 2045-2310 hours were not significantly different from random and were not related to availability ($P > 0.05$; Table 3).

These transects were located in reach 3 between RK 512-518 which was the shallowest cross section with the highest velocities. Fish in transects located in reach 2 between RK 497-500 selected depths that were significantly different from random and from water velocities available in the cross section ($P < 0.01$; Table 3). Median depths of fish in the deeper reach shifted from 5.5 m at 1900-1955 hours to 11.6 m at 2224-2305 hours (Table 4; Figure 4B, D).

Juvenile American shad distribution

Fish density during night sampling in John Day Reservoir was considerably higher than that observed during daytime sampling. Fish density during night samples ranged from 22-121 fish/10,000 m^3 of water for transects that began at 2042-0107 hours (Table 2). Density observed during the day ranged from 3-18 fish/10,000 m^3 water for transects that began at 1200-1836 hours.

Fish located by echosounder were distributed randomly across the range of water velocities available in one of four groups of transects. In three groups of transects starting at 1200, 2042, and 0020 hours, the water velocities selected by fish were significantly different from a random distribution ($P < 0.05$; Table 3). In a fourth group of transects sampled beginning at 1752 hours, the frequency of water velocities selected by fish was not distributed significantly different from random ($P > 0.05$; Table 3).

The frequency of water velocities selected by fish did not reflect the frequency of water velocities available in reservoir cross sections. The water velocities available and the water velocities selected by fish were significantly different in all groups of transects sampled in John Day Reservoir ($P < 0.01$; Table 3). Density of fish in transects started between 2042 and 0107 hours, during darkness, tended to be higher in water velocities 2-12 cm/s compared to the 12-24 cm/s velocity range

Table 4.-Distribution medians of subyearling chinook salmon and American shad associated with velocity and depth in hydroacoustic transects in McNary and John Day reservoirs.

			Velocity (cm/s)		Depth (m)	
Group	Date	Start time	Fish median	Velocity median	Fish median	Depth median
			Subyearling Chinook salmon			
1	7-11-92	1248	4.4	23.2	6.2	6.0
2	7-08-92	1900	19.9	17.1	5.5	7.4
3	7-12-92	2045	25.3	21.9	5.9	6.6
4	7-09-92	2224	15.1	19.7	11.6	8.2
			American shad			
5	g-01-92	1200	27.5	11.5	15.5	10.9
6	8-31-92	1752	15.6	13.0	13.2	10.7
7	g-02-92	2042	13.5	12.4	13.1	10.4
8	g-03-92	0020	35.5	8.3	9.7	10.9

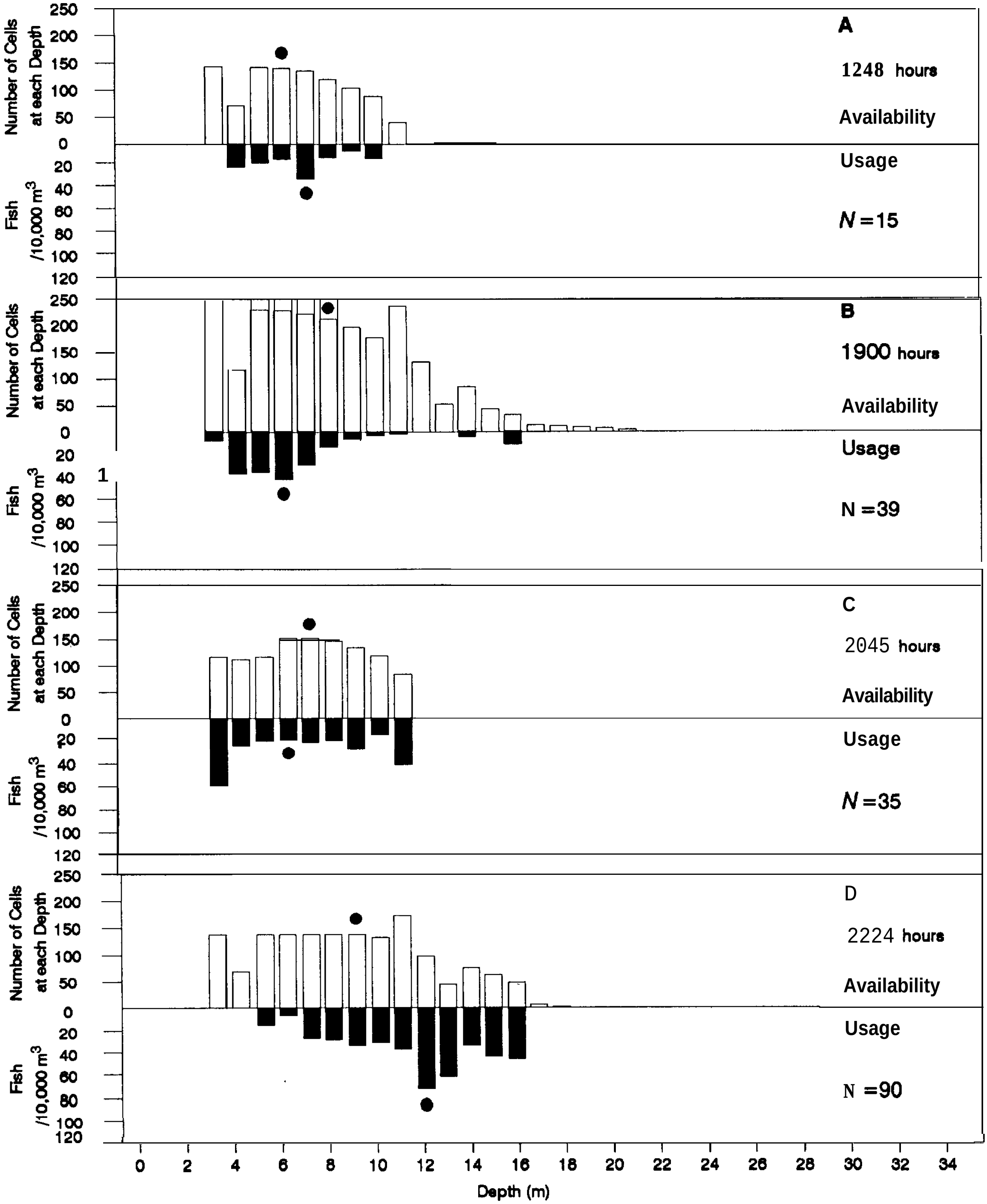

Figure 4.— Frequency histograms of available depth cells and associated fish density by depth for hydroacoustic surveys performed in McNary Reservoir, 1992. Medians are denoted as (●).

(Figure 5). Exceptions to this were very high densities at the highest velocities.

The frequency distribution of fish relative to depth strata sampled differed between transects surveyed during the day and those surveyed at night. In the transects sampled during the day starting at 1200 and 1753 hours, the frequency of depth cells selected by fish was not significantly different from a random distribution ($P > 0.05$; Table 3). The depth cells selected by fish on transects starting at 2042 and 0020 hours were not randomly distributed ($P < 0.05$; Table 3).

The depths selected by fish and those available in the reservoir cross section were significantly different (P c 0.05; Table 3). Although the median depth of the transects surveyed was similar in all transects, 10.4-10.9 m, the median depth of fish detected shifted from 15.5 m at midday to 9.7 m for transects starting near midnight (Table 4; Figure 6).

Discussion

We assumed that most hydroacoustic targets located in McNary Reservoir during July were subyearling chinook salmon and most targets located in John Day Reservoir during August and early September were American shad. Species composition of trawl catches, fish passage indices, and the limits we used on target strengths of -58 db to -46 db support these conclusions.

Although the total volume of water sampled during 1992 hydroacoustic surveys was large, encounters with target fish were quite low, especially during the early summer surveys conducted in McNary Reservoir. This is partially due to overall fish densities in the system at the time of sampling. However, it is also a result of the echo sounder beam structure, narrow at the surface and increasing in width with depth, resulting in inefficient sampling of the upper three meters of the water column. To accurately evaluate this portion of the water column an emphasis on improved side looking techniques or modifications in equipment need to be tested and evaluated. The inability to accurately sample shallow nearshore areas is also **a** concern. The importance of these areas of the reservoirs in regards to subyearling chinook salmon migration and rearing is of interest.

The water velocities that fish were located at were not random and did not reflect availability. In most groups of transects we found that frequency of velocities selected by fish were significantly different from random. Furthermore, the water velocities selected by fish were significantly different from the expected frequency based on water velocities available in the reservoir cross sections. The range of water velocities measured was relatively narrow in all transects surveyed (< 50 cm/s).

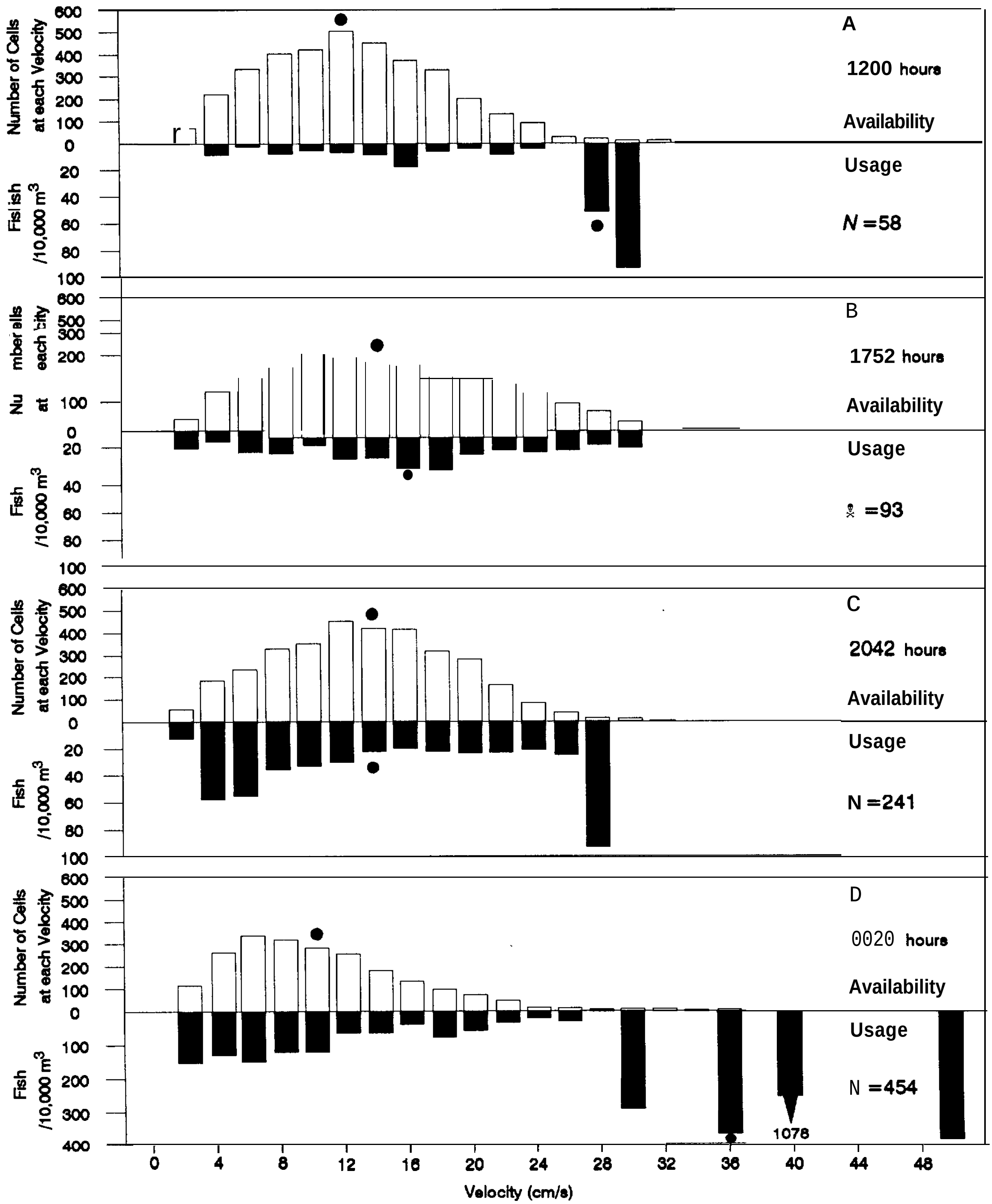

Figure 5.— Frequency histograms of available velocity cells and associated fish density by velocity for hydroacoustic surveys performed in John Day Reservoir, 1992. Medians are denoted as (●).

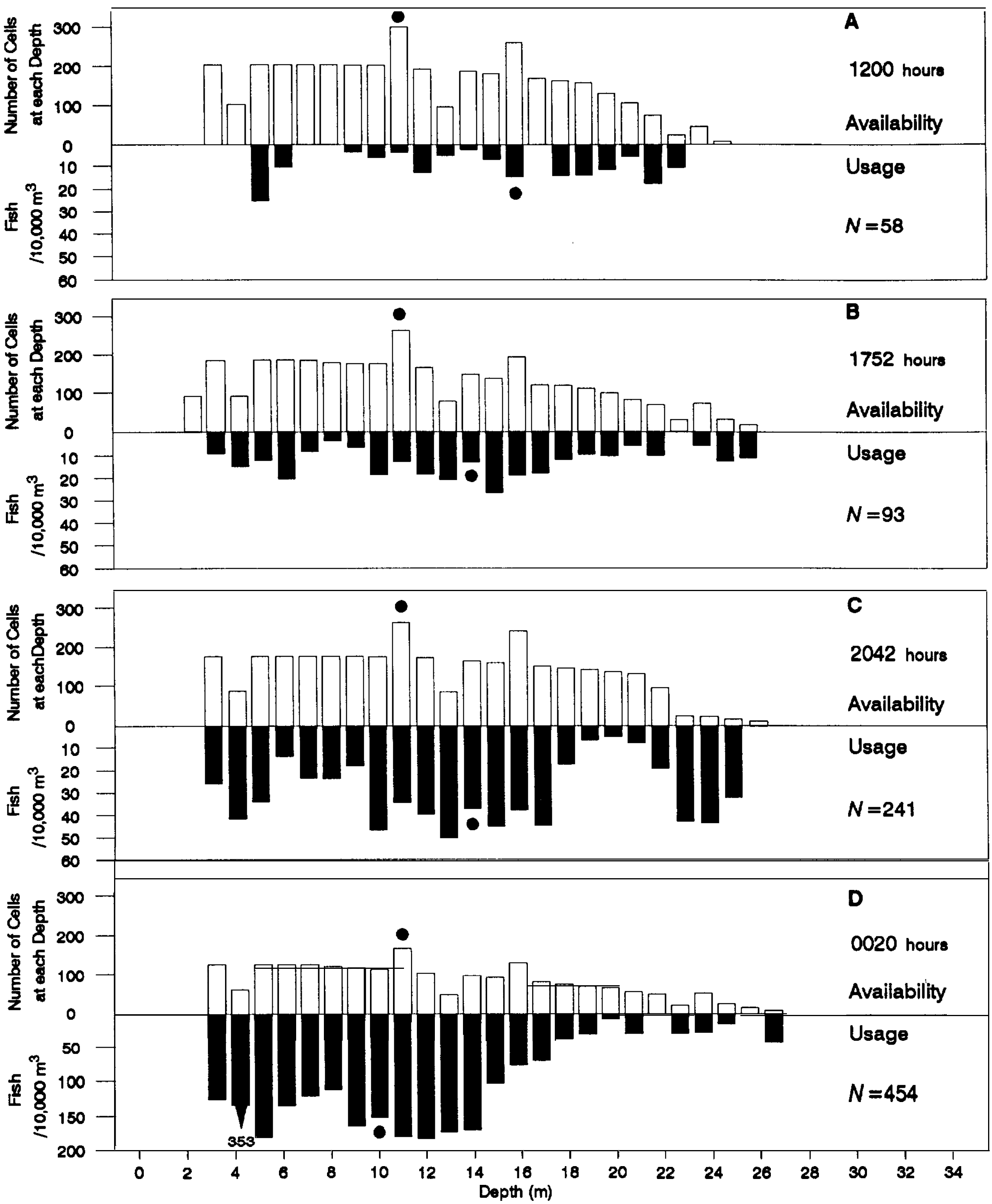

Figure 6.— Frequency histograms of available depth cells and associated fish density by depth for hydroacoustic surveys performed in John Day Reservoir, 1992. Medians are denoted as (●).

Discerning patterns of biological significance within this relatively narrow range of water velocities may be difficult.

In summary, we integrated and deployed a system using a hydroacoustic fish stock assessment system to locate subyearling chinook salmon in reservoirs, an ADCP to measure water velocities, and a GPS to provide locations and night navigation. Data presented in this chapter are preliminary, but representative of the data collected during 1992 field work. Concerns about equipment capabilities, sampling techniques, and data analysis will continue to be addressed.

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CHAPTER EIGHT

Osmoregulatory Performance and Marking of Subyearling Chinook Salmon at McNary Dam to Estimate Adult Contribution

by

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Introduction

Research conducted at McNary Dam from 1981 to 1983 determined that subyearling chinook salmon *Uncorhynchus tshawytscha* which emigrated earlier in the summer exhibited greater adult contribution than did those emigrating later in the summer (Giorgi et al. 1990). No physical or biological factor could be isolated as a causal factor for this phenomenon even though **a** primary objective of the study was to examine the influence of flows on juvenile emigration and survival. Giorgi et al. (1990) attributed this failure to an inability to recover sufficient numbers of marked fish at John Day Dam to estimate their travel time through John Day Reservoir and the interaction among flow, temperature, fish size, physiological development, and origin of the fish.

This study task was initiated in an attempt to resolve the questions pertaining to the influence of summer flows on the emigration of subyearling chinook salmon and their contribution as adults. The primary objectives for this second year of study were to mark and release sufficient numbers of subyearling chinook salmon at McNary Dam to estimate their travel time through John Day pool and to determine if released groups remained temporally discrete during emigration. Another objective was to describe the physiological development of fish marked and released at McNary Dam and to relate that to travel time and future adult returns.

Methods

Marking and Release

Juvenile subyearling chinook salmon were collected from the juvenile fish collection facility at McNary Dam. The dam is equipped with traveling screens to divert juvenile fish from the turbine intakes into gatewells and to raceways. Fish entering the collection facility were sub-sampled by operation of a timed gate in the conduit moving fish to the holding raceways. Each group of fish **was** collected by repeated sub-sampling during a 24 h period starting at 0700 hours. The sub-sample rate ranged from **5%** to **20%** of the total number of fish diverted.

Subyearling chinook salmon were marked with coded wire tags (CWT) and branded with cold brands (Jefferts et al. 1963; Mighell 1969). Fish were anesthetized with a preanesthetic of benzocaine (ethyl P-aminobenzoate) and an anesthetic of tricaine methanesulfonate (MS-222) similar to that described by Matthews (1986). Juvenile fish were then sorted by species and marked with CWT and cold brands. Three segments of the emigration were marked; early, middle, and late. For each segment of the migration, three CWT codes were used resulting in a total of nine CWT codes released in 1992. During each day of marking, fish were marked with cold brands using a unique combination of a character, location, and rotation. The cold brand identified the fish for subsequent determination of migration time from McNary Dam to John Day Dam. Marked fish were released into the fish bypass system at McNary Dam between 2200 and 2300 hours on the day of marking. At John Day Dam juvenile salmon were collected using two air-lift pumps (Brege et al. 1990) and the brands on recaptured fish were recorded.

The marking program included measures to ensure the quality of subyearling chinook salmon released at McNary Dam. Fish that; were previously branded or adipose fin clipped and CWT tagged, descaled, or had injuries likely to result in mortality were not marked (Wagner 1993). Fish with fork lengths < 55 mm were also not marked. One hundred fish per day were held for 48 h to measure delayed mortality and coded wire tag loss from the first and second replicates and about 50 fish per day were held from the third replicate. Fish surviving the delayed mortality test were transported downstream by barge or truck to prevent confounding of migration time estimates to John Day Dam.

Travel time of branded replications of fish was estimated to the nearest day by the method used by the Fish Passage Center i.e., the difference between the median date of release at McNary Dam and the date nearest the median date of recovery based on the passage indices at John Day or Bonneville dams. However, we only estimated travel time to the nearest day and did not interpolate to the nearest tenth of a day. Flow and temperature during travel time was estimated by averaging the discharge and temperature at John Day Dam from the day after fish release at McNary Dam through the median day of recovery at John Day Dam. Since recapture data were not normally distributed, nonparametric tests were used in statistical analyses.

Physiology

Samples were collected for gill Na^+,K^+-adenosine triphosphatase (ATPase) analysis from Priest Rapids State Fish Hatchery brand groups and from wild subyearling fall chinook salmon in the Hanford Reach of the Columbia River to assess smoltification of premigrants. Priest Rapids fish were sampled before release and Hanford fish were sampled coincidentally with a Washington Department of Fisheries marking study. Gill samples were collected again from Priest Rapids and Hanford brand groups at McNary Dam to measure ATPase activities of emigrants.

Twenty-four-hour seawater challenges were employed to evaluate the physiological status of emigrating subyearling chinook salmon marked at McNary Dam. The general procedures of the seawater challenges followed Blackburn and Clarke (1987). Recirculating flow-through systems were used for challenged and control fish. The seawater system was composed of eight plastic 80-L containers which drained into a sump reservoir and a pump recirculated salt water from the sump to the plastic containers. The control system was identical to the seawater system except two containers were used. Chillers were placed in sump reservoirs to maintain water temperature at 18.3°C. Diaphragm pumps and air stones supplied air to each tank.

Actively emigrating subyearling chinook salmon were collected at the McNary Dam fish collection facility coincidentally with marking. Three separate challenges were conducted to characterize the seawater adaptability of migrants during the early, middle, and late portions of the outmigration. Random samples of 10 anesthetized fish were weighed, measured (FL), and distributed to each tank. Fish were allowed to acclimate for 24 h prior to being challenged.

Artificial sea salt was dissolved and added to the sump reservoir of the seawater system to infuse salt water into the tanks without handling or disturbing the fish. A desired salinity of 30 parts-per-thousand was usually achieved within one hour. Unchallenged control fish were maintained in fresh water.

At the end of a 24-h challenge, fish were immobilized in their tanks with 30 mg/L MS222. Anesthetized fish were weighed, measured, rinsed in fresh water., and their tails blotted dry before being severed. Blood was collected from the caudal artery in ammonium heparinized Natelson tubes, centrifuged, and the plasma was frozen immediately in liquid nitrogen. In addition, gill filaments were collected for determination of Na^+,K^+-ATPase activity.

Blood plasma was analyzed for Na' and K^+ by flame photometery. Plasma cortisol was analyzed by radioimmunoassay (Redding et al. 1984) and gill Na^+,K^+-ATPase activity was measured using a microassay (Schrock et al. 1994). Group means were calculated for control and test fish for the three challenges. Means were compared between challenges using analysis of variance (ANOVA) and Tukey's test while within-challenge comparisons were made using t-tests by the Cochran-Cox approximation for plasma Na' and K^+ and t-tests for plasma cortisol and gill ATPase activity. The significance level for all tests was $P < 0.05$.

Results

Marking, Release, and Recapture

The median date of subyearling chinook salmon emigration past McNary Dam in 1992 was 29 June (Figure 1), which is 4 days earlier than the 1984-90 median. The 10% passage was four days later and the 90% passage was four days earlier than the 1984-90 mean (Fish Passage Center 1993). Based on recaptures of wild subyearling chinook salmon that were freeze branded, tagged with passive integrated transponders (PIT) and released in the Hanford reach on 8 June (median date), 10% , 50%, and 90% passage at McNary Dam occurred on 25 June, 3 July, and 18 July, respectively. The median dates of passage at McNary Dam of branded subyearling fall chinook salmon released from Priest Rapids State Fish Hatchery between 12 and 24 June ranged from 30 June to 6 July. The median date of passage for branded subyearling summer chinook salmon released on 19 June from Wells State Fish Hatchery was 28 July. A total of 1,549 subyearling chinook were PIT tagged and released from 15 June to 14 August for the first time from Rock Island Dam in 1992. Of these, 4.9% were detected at McNary Dam (Fish Passage Center 1993). The 10, 50, and 90% passage dates of all hatchery fish combined at McNary Dam were 26 June, 2 July, and 18 July. Passage dates at McNary Dam indicate that migration timing was similar for hatchery fish and wild fish produced in the Hanford Reach.

A total of 105,250 subyearling chinook salmon collected at McNary Dam were freeze branded, coded wire tagged, and released in the tailrace (Table 1; Appendix 9). An additional 2,750 marked fish were transported after being retained for 48 h to estimate delayed mortality and CWT loss, which ranged from 0.6 to 0.7%. The group of 35,095 early migrants were marked with 9 unique brands from 16 to 24 June when the cumulative passage index increased from 5% to 20%. The middle group of 35,052 emigrants were marked with 10 unique brands from 2 to 11 July when the passage index increased from 63% to 84%. The late group of 35,103 emigrants were marked with 14 unique brands from 17 to 30 July when the passage index increased from 94% to 97%.

Columbia River flows at McNary Dam decreased from about 170 thousand cubic feet per second (KCFS) in early June to about 90 KCFS in late August while water temperature increased from 16°C to 22°C (Figure 1). Flows during June and July were about 50% of the 40 year average and in August flows increased to about 75% of the 40 year average.

The number of subyearling chinook salmon recaptured at John Day Dam ranged from 36 to 118 fish for the nine CWT replications and from 128 to 324 for the early, middle, and late groups (Figure 2; Table 2). Estimated travel times were 15, 21, and 15

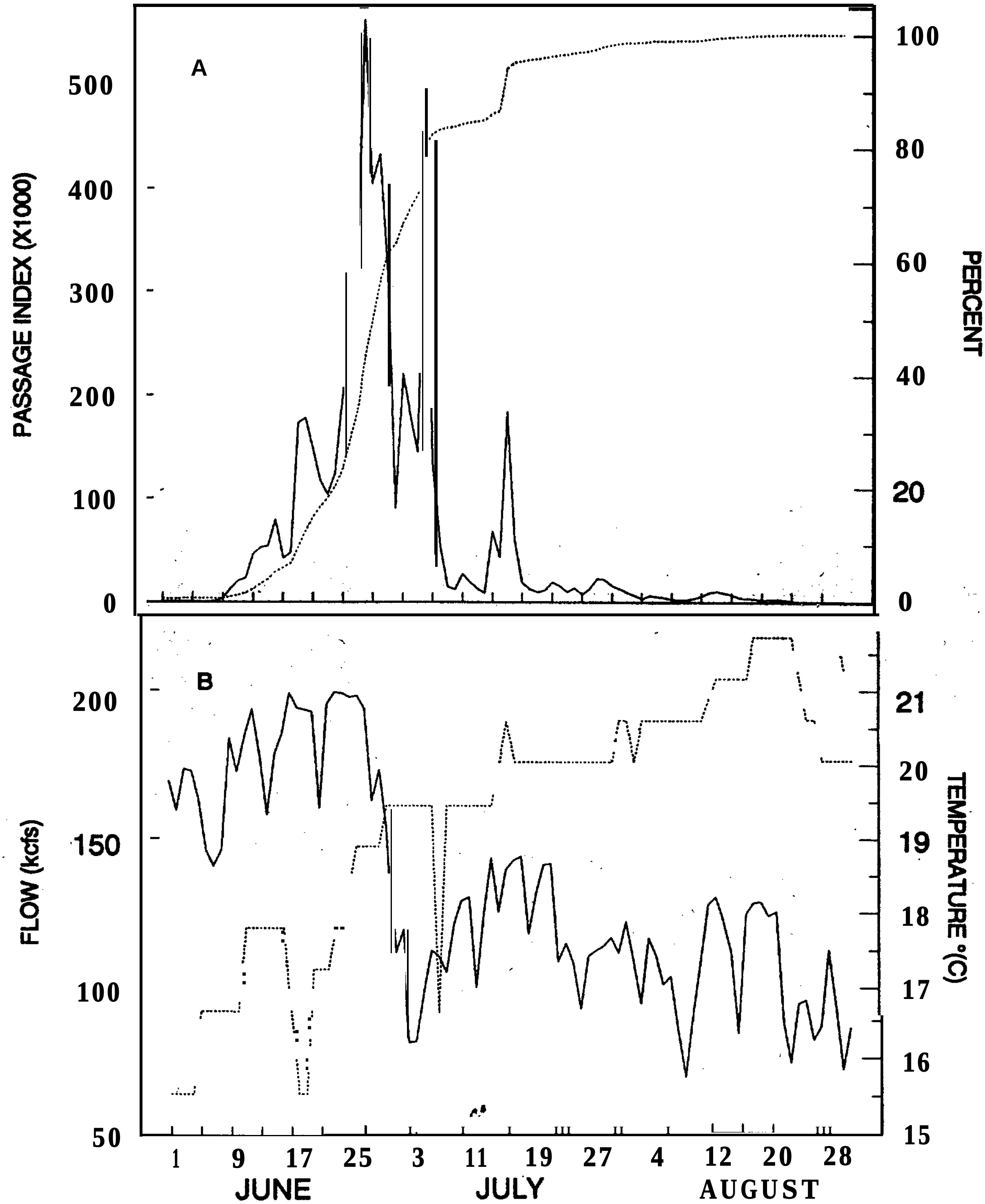

Figure 1.-Daily (solid line) and cumulative (dotted line) passage index (x1000) of subyearling chinook salmon (A) and daily flow (solid line) and temperature (dotted line: B) at McNary Dam, 19-92.

Table 1.-Date, coded wire tag (CWT) code, and number of subyearling chinook salmon released in the McNary Dam tailrace and the number of fish held for 48 h with their tag loss and mortality prior to transportation, 1992.

Date	CWT Code	Marked & Released	Marked & Held	Mortality	Tag Loss	Percent Loss
Jun 16-18	29-52	11,767	300	0	0	0
Jun 19-21	29-54	11,259	300	3	1	0.3
Jun 22-24	29-53	12,069	305	0	0	0
Sub-Total		35,095	905	3	1	0.1
Jul 2-4	29-51	11,700	300	2	0	0
Jul 5-7	29-50	11,786	300	0	0	0
Jul 8-11	29-49	11,566	400	4	0	0
Sub-Total		35,052	1,000	6	0	0
Jul 17-18	29-48	11,386	200	2	10	5.0
Jul 19-25	29-46	11,766	350	8	5	1.4
Jul 26-30	29-47	11,951	295	1	0	0
Sub-Total		35,103	845	11	15	1.8
Total		105,250	2,750	20	16	0.6

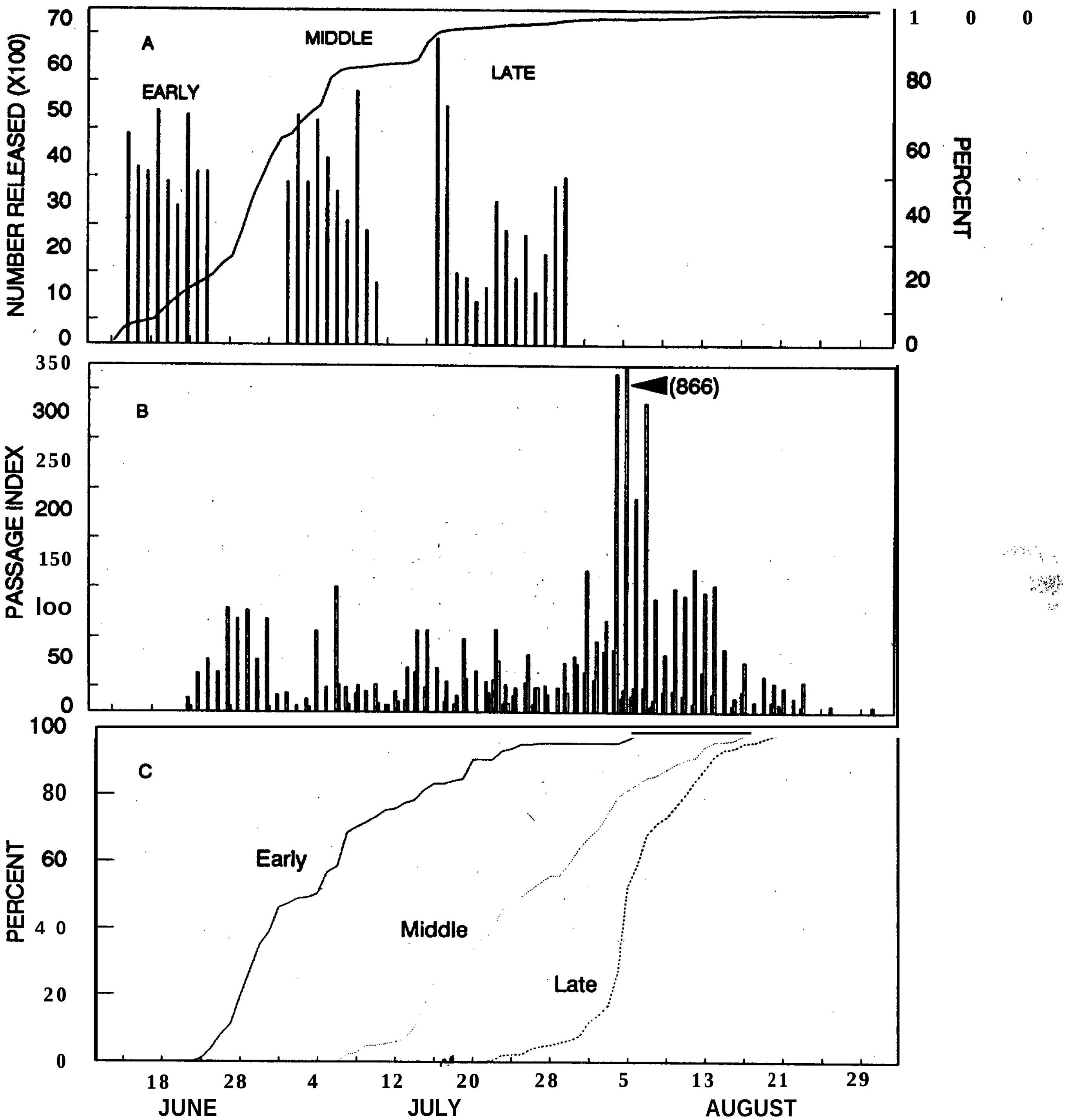

Figure 2.-Number of subyearling chinook salmon marked and released at McNary Dam with cummulative percent passage index (A) and the passage index of early, middle, and late emigrating marked groups (B) and the cummulative percent frequency of each group (C) recovered at John Day Dam, 1992.

Table 2.-Median dates and number of subyearling chinook salmon released at McNary Dam and the number recovered, passage index (PI), and percent detected (%) at John Day and Bonneville dams, 1992.

McNary Dam Release			Recovery at John Day				Recovery at Bonneville			
CWT Group	Med. Date	Number	Med. Date	Number	PI	%	Med. Date	Number	PI	%
29-52	17 Jun	11,767	28 Jun	46	511	4.3	29 Jun	31	93	0.8
29-54	20 Jun	11,259	5 Jul	36	336	3.0	2 Jul	75	214	1.9
29-53	23 Jun	12,069	8 Jul	46	431	3.6	3 Jul	74	202	1.7
Early	20 Jun	35,095	5 Jul	128	1,278	3.6	2 Jul	180	509	1.5
29-51	3 Jul	11,700	17 Jul	39	365	3.1	21 Jul	55	106	0.9
29-50	6 Jul	11,786	1 Aug	64	556	4.7	19 Jul	82	174	1.5
29-49	9 Jul	11,566	1 Aug	37	304	2.6	22 Jul	116	230	2.0
Middle	6 Jul	35,052	27 Jul	140	1,225	3.5	21 Jul	253	510	1.5
29-48	17 Jul	11,386	5 Aug	97	767	6.7	7 Aug	60	130	1.1
29-46	23 Jul	11,766	7 Aug	109	949	8.1	20 Aug	60	100	0.8
29-47	29 Jul	11,951	10 Aug	118	943	7.9	17 Aug	120	236	2.1
Late	23 Jul	35,103	7 Aug	324	2,659	7.6	16 Aug	240	466	1.4

days for the early, middle, and late groups, respectively. The Kruskal-Wallis test indicated the time of emigration for the three groups past John Day Dam was significantly different (X^2 = 196.6) and Tukey's test indicated all three groups were significantly different from each other.

The number of fish recaptured at Bonneville Dam ranged from 31 to 120 for the nine CWT replications and 180 to 253 for the three groups (Table 2). Emigration time for the three groups past Bonneville Dam was significantly different (X^2 = 68.62) and each group was different from each other. The median dates of recapture for the replications at John Day and Bonneville dams indicated the fish traveled rapidly through the Dalles and Bonneville reservoirs compared to travel time through John Day reservoir. Travel time was not significantly correlated with flow, temperature, gill ATPase activity, median release date, or fork length (Table 3).

Physiology

Gill ATPase activity of premigrants from Priest Rapids State Fish Hatchery and from the Hanford Reach was low but rose substantially by the time of recapture at McNary Dam. Mean gill ATPase activities of prerelease brand groups at Priest Rapids on 11 and 17 June were 9.2 and 8.6 μmol Pi/(mg protein)/h, respectively. These same brand groups were recaptured at McNary Dam from 27 June to 15 July and had mean gill ATPase activities of 27.1 and 26.8 μmol Pi/(mg protein)/h. Subyearling chinook salmon branded in the Hanford reach on 3 and 10 June had gill ATPase activities of 11.5 and 14.0 μmol Pi/(mg protein)/h. These fish were collected at McNary Dam from 21 June to 28 July and had mean gill ATPase activities of 31.0 and 31.4 μmol Pi/(mg protein)/h. Gill ATPase activities of migrants marked at McNary Dam ranged from 20.0 to 34.3 in 1992 while in 1991 levels ranged from 14.6 to 30.3 μmol Pi/(mg protein)/h (Figure 3).

All subyearling chinook salmon used in seawater challenges exhibited the silvery appearance of smolts. Group means of plasma Na' of challenged fish were 153.2 mmol/L for the early challenge, 150.3 for the middle, and 153.6 for the late challenge (Table 4, Figure 4). Of the 223 fish challenged only 5 died during testing.

ANOVA of plasma Na' values from the early challenge were significantly different than those of the middle, but not the late challenge. The middle and late challenge plasma Na' concentrations were not different from each other. Control values from the early challenge were significantly different from the middle and late challenge but there was no difference between the middle and late challenges for plasma Na'. Comparisons within challenges showed that seawater challenged fish had

Table 3.-Correlation of subyearling chinook salmon travel time from McNary Dam to John Day Dam with median release date, flow, temperature, ATPase activity, and fork length (FL) of coded wire tagged (CWT) groups, 1992.

CWT Group	Travel Time (d)	Median Date	Flow (kcfs)	Temp. (C)	ATPase Activity	FL (mm)
Early						
29-52	11	17 June	193	18.4	27.2	110
29-54	15	20 June	156	18.3	22.0	108
29-53	15	23 June	140	la.3	27.6	106
Middle						
29-51	14	3 July	121	la.7	31.5	106
29-50	26	6 July	123	19.8	34.3	106
29-49	23	9 July	125	20.0	30.6	109
Late						
29-48	**19**	17 July	118	20.7	23.6	114
29-46	15	23 July	112	20.9	20.5	118
29-47	12	29 July	104	20.9	20.0	125
r		0.123	-0.333	0.267	0.584	-0.385

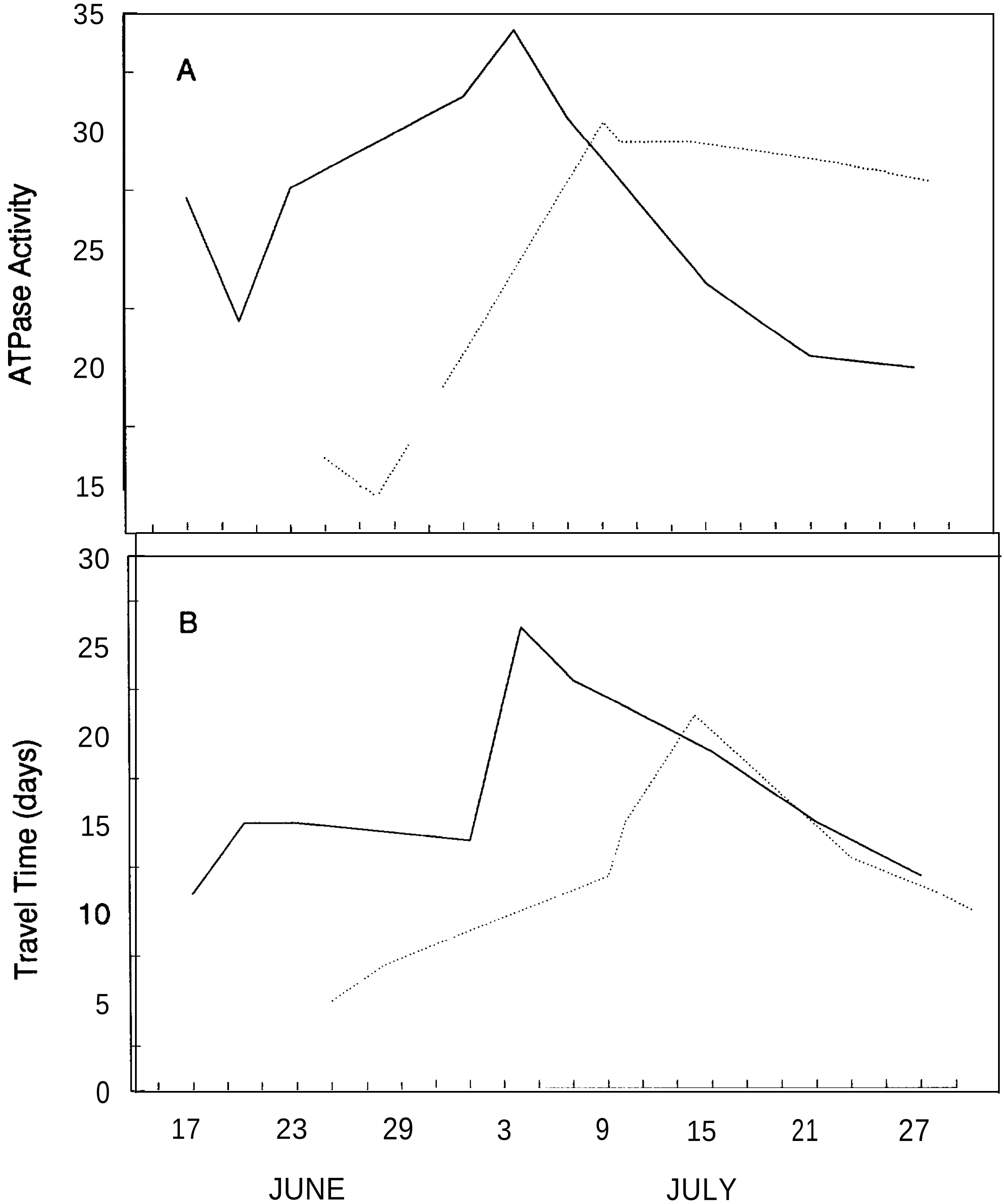

Figure 3.—Gill ATPase activity (A) and travel time to John Day Dam (B) calculated from median date of release of groups of subyearling chinook salmon marked at McNary Dam in 1991 (dotted line) and 1992 (solid line).

Table 4.-Mean plasma **Na'** (mmol/L), plasma cortisol (ng/ml), and gill ATPase activity (μmol Pi/(mg protein)/h) from subyearling fall chinook migrants subjected to 24-h seawater challenges at McNary Dam, 1992.

Date	Test water	Level	N	Std err	cv	Mort
		Plasma Na'				
6-25	seawater	153.2	69	1.164	6.31	4
6-25	fresh	140.2	18	1.208	3.66	0
7-9	seawater	150.3	78	0.545	3.20	0
7-9	fresh	148.1	20	1.182	3.57	0
7-23	seawater	153.6	76	0.837	4.75	1
7-23	fresh	147.5	19	0.964	2.85	1
		Plasma Cortisol				
6-25	seawater	214	28	11.813	29.23	4
6-25	fresh	193	16	11.419	23.66	0
7-9	seawater	217	31	7.527	19.31	0
7-9	fresh	148	20	15.440	46.69	0
7-23	seawater	211	33	10.418	28.38	1
7-23	fresh	209	19	8.934	18.67	1
		ATPase				
6-25	seawater	31.2	30	1.723	30.20	4
6-25	fresh	29.5	20	2.029	30.78	0
7-9	seawater	29.6	29	1.384	25.15	0
7-9	fresh	27.5	20	2.058	33.52	0
7-23	seawater	27.3	30	1.514	30.32	1
7-23	fresh	16.8	18	1.698	42.96	1

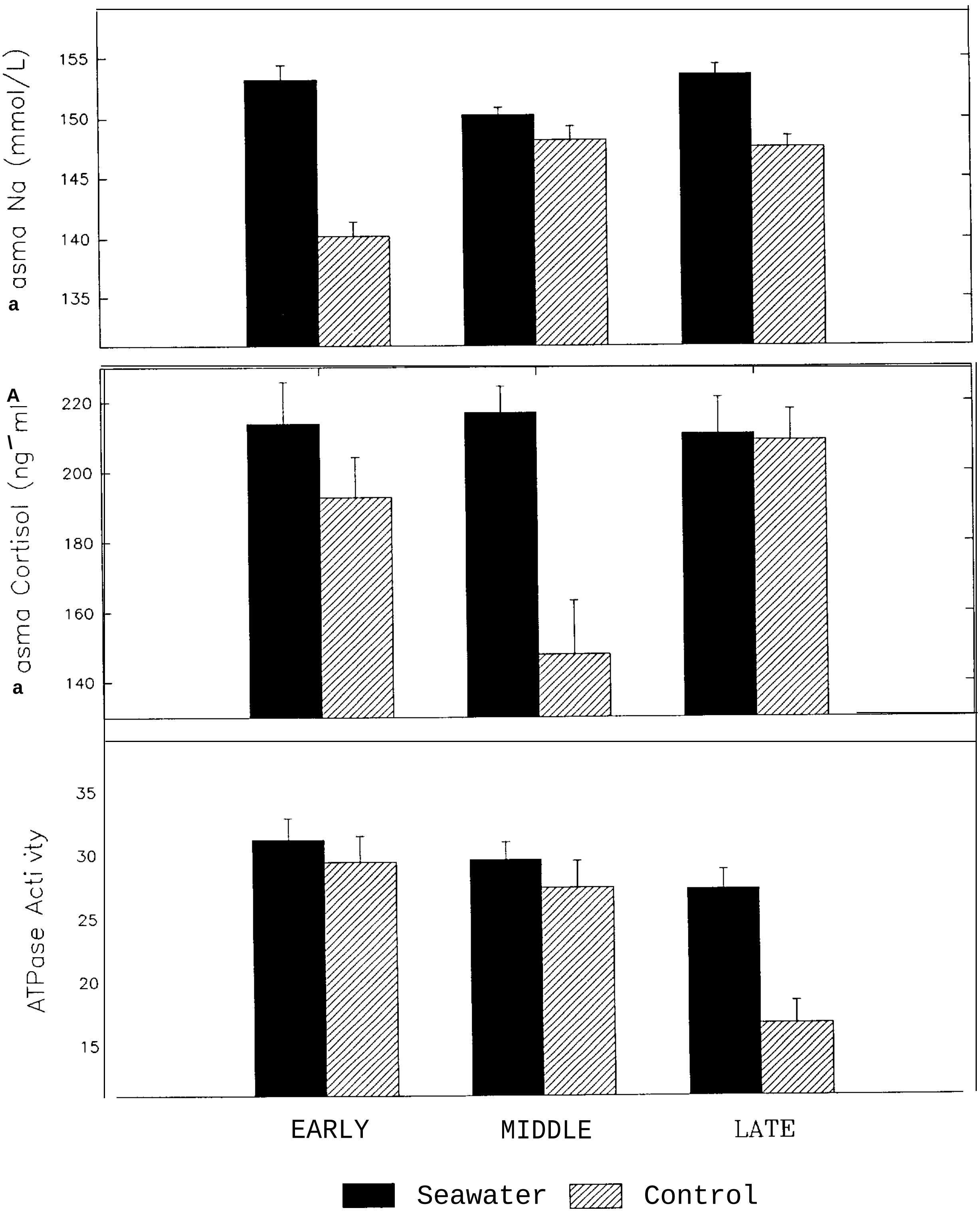

Figure 4 .-Physiological responses, with standard error bars, of subyearling chinook salmon exposed to seawater and fresh water at McNary Dam during the early (25 June), middle (9 July), and late (23 July) portions of the 1992 outmigration.

significantly higher plasma Na^+ values than control fish in the first and third challenges but not in the second challenge. There was a small decrease in plasma K^+ concentration from the early to late portion of the run but no differences were found between challenged and control fish.

There were no significant differences in plasma cortisol values of challenged fish between any portions of the outmigration. Mean plasma cortisol values of challenged fish showed a slight decrease from 219 ng/ml in the early portion of the run to 210 ng/ml in the late part of the run (Table 4, Figure 4). Control fish values were slightly lower than challenged fish values during all challenges. Low plasma cortisol values of control fish from the middle challenge resulted in significant differences in any comparison involving this group, otherwise, there were no differences between control values or between challenge and control values. Plasma cortisol was correlated with plasma Na^+ when cortisol from fish in seawater were combined ($r = 0.407$). No correlations existed between plasma cortisol and plasma Na^+, gill ATPase activity, length, or weight in control fish.

ATPase activities were typical of smolted fish, but showed a slight decline from the early to late portions of the outmigration (Table 4, Figure 4). Seawater challenged fish had higher activities than control fish, but were not significantly different except during the late challenge. Seawater gill ATPase activities were not significantly different over time, but low activities from the late control group resulted in significant differences in any comparison involving this group. In seawater fish, ATPase activity was significantly correlated with length ($r = -0.285$) and weight ($r = -0.266$) and in control fish with plasma K^+ ($r = 0.329$).

Discussion

Travel time from McNary to John Day Dam was correlated with certain physical and physiological variables in 1991, but no significant correlations existed in 1992. The reason for this may be that travel times in 1992 showed no distinct pattern of either increasing or decreasing over time. This made the likelihood of obtaining any significant correlations involving travel time improbable, especially given the small sample sizes used in correlation analyses.

Estimated travel times of subyearling chinook salmon from McNary to John Day Dam did not follow the paradigm that travel time decreases with increased flow or the expectation that rapid travel time would be associated with relatively high gill ATPase activities. Travel times increased from the early to middle portions of the outmigration as flows decreased, but then became shorter during the late portion of the run as flows continued to decline. ATPase activity followed a similar trend (Figure 3). During the latter portion of the outmigration several factors such as increased water temperature, increased fish size, and stock differences may have contributed to this phenomenon. In addition, Skalski (1989) has shown that various assumptions related to passage index calculation at John Day Dam are often violated due to shifts in dam operations and subsequently may lead to biased travel time estimates. This may explain the seemingly contradictory results obtained in 1992.

Subyearling chinook salmon migrating past McNary Dam during the early, middle, and late portions of the outmigration in 1992 appeared to be fully smolted and were physiologically adapted to sea water. Although statistical differences were found between plasma **Na'** values, biologically there appeared to be no trend in seawater adaptiveness. Fish in all three seawater tests performed equally well as evidenced by low mortality and ability to regulate plasma Na' below 165 mmol/L, the value given by Clarke and Shelbourn (1985) for characterizing chinook salmon smolts. Higher plasma Na' values in challenged fish compared to freshwater control groups may be attributed to the requirement of more than 24 h to further lower plasma Na' or else plasma Na' is maintained at a higher equilibrium in sea water (Conte and Wagner 1965).

Plasma cortisol has been implicated in the maintenance of water-electrolyte balance in hyperosmotic media, but its role in accomplishing this remains unclear (Hoar 1988). No relationship was established between plasma cortisol and seawater adaptiveness in subyearling chinook salmon challenged at McNary Dam. All significant differences in plasma cortisol comparisons involved the middle challenge control group which contained a number of comparatively low values from one tank. The reason for this is unknown. The rapid surge in plasma cortisol upon entry into sea water observed in coho salmon *O. kisutch* (Redding et al. 1984; Young et al. 1989) was not observed in subyearling chinook salmon challenged at McNary Dam. Plasma cortisol may have surged then returned to prechallenge levels before samples were collected 24 h later. Alternatively, plasma cortisol levels elevated by stress induced by the McNary Dam collection facility may have minimized any seawater response. Plasma cortisol values of both challenged and control fish were high compared to the baseline value of 100 ng/ml given by Schreck et al. (1984) for unstressed fish in the system. However, fish should have recovered from collection stress in 24-48 h (Maule et al. 1988). Regardless of any stress confounding that may have affected challenge results, there were no differences between challenged and control levels, except during the second challenge, that would indicate a seawater response by plasma cortisol.

The rapid rise in gill ATPase activity exhibited by Priest Rapids and wild Hanford fish was likely due to physiological change during emigration (Zaugg et al. 1985). Although gill ATPase activity declined during the latter part of the emigration fish were still able to adapt to sea water. Despite comparatively low activities in control fish during the late portion of the run, ATPase activities increased significantly upon seawater entry. This is consistent with the findings of other investigators (see review in Folmar and Dickhoff 1980) relating to sea water's stimulating effect on ATPase activity.

There appeared to be no relationship between seawater performance of subyearling chinook salmon and river flow and temperature at McNary Dam. However, gill ATPase activity declined during the seawater challenge period as river flows declined and water temperatures increased. The decrease in gill ATPase activities with increasing temperature, reviewed by Wedemeyer et al. (1980), may explain the gill ATPase activity decline in this study. In addition, the decline in gill ATPase activities may have resulted from smolts migrating after their physiological peak due to longer travel times caused by lower flows.

The rise and subsequent decline in gill ATPase activities of run-at-large fish sampled at McNary Dam was similar to the increase and subsequent decrease in travel time during the study period. The observed trend of increasing gill ATPase activities with increasing travel times was unexpected. The definition and cause for this pattern may be elucidated after collecting additional data in upcoming years.

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LIST OF APPENDICES

Appendix 1. -Snake River average daily discharge at Anatone gage, Washington (1991-1993).

DATE	AUG-91 TO JUN-92 AVG	AUG-92 TO JUN-93 AVG
18-Aug	11700	9650
19-Aug	11900	9690
20-Aug	14000	9620
21-Aug	12200	9490
22-Aug	11400	9440
23-Aug	11300	9630
24-Aug	11400	9570
25-Aug	11000	9640
26-Aug	11300	9580
27-Aug	11700	9510
28-Aug	12000	9510
29-Aug	12100	9440
30-Aug	12600	9390
31-Aug	13500	9330
01-Sep	13000	9260
02-Sep	12800	9260
03-Sep	12700	9270
04-Sep	12800	9220
05-Sep	13800	9230
06-Sep	13500	9310
07-Sep	17400	9410
08-Sep	17300	9490
09-Sep	19600	9590
10-Sep	22200	9750
ll-Sep	22400	9850
12-Sep	22700	9490
13-Sep	23100	9640
14-Sep	23300	9980
15-Sep	23200	10100
16-Sep	23200	10500
17-Sep	23100	10800
18-Sep	23100	10500
19-Sep	23200	10500
20-Sep	16200	10300
21-Sep	18300	10400
22-Sep	16600	11000
23-Sep	16600	10200
24-Sep	17600	10100
25-Sep	16800	10400
26-Sep	15600	11000
27-Sep	16800	11400
28-Sep	15900	11600
29-Sep	15000	11800
30-Sep	14400	12200
01-Oct	15600	13650
02-Oct	14500	15100
03-Oct	15100	14700
04-Oct	15000	14200
05-Oct	16100	14300

Appendix 1. (Continued).

DATE	AUG-91 TO JUN-92 AVG	AUG-92 TO JUN-93 AVG
06-Oct	15400	14500
07-Oct	15500	14600
08-Oct	15900	14300
09-Oct	16400	14100
10-Oct	15900	14000
11-Oct	14700	14100
12-Oct	14500	14200
13-Oct	14300	14200
14-Oct	14600	14200
15-Oct	16400	14300
16-Oct	15100	14500
17-Oct	14200	14100
18-Oct	14800	14200
19-Oct	14400	14200
20-Oct	14200	14300
21-Oct	14200	14400
22-Oct	14000	14400
23-Oct	14200	14100
24-Oct	14300	13400
25-Oct	14200	13200
26-Oct	14100	13200
27-Oct	14200	13200
28-Oct	14200	13200
29-Oct	14400	13300
30-Oct	14200	13300
31-Oct	14000	13700
01-Nov	13900	14000
02-Nov	13900	14300
03-Nov	14100	14400
04-Nov	13900	14200
05-Nov	14000	14100
06-Nov	15200	14000
07-Nov	16100	13900
08-Nov	16100	13900
09-Nov	15900	14100
10-Nov	16000	14100
11-Nov	16100	13900
12-Nov	16000	13700
13-Nov	16300	13600
14-Nov	16700	13500
15-Nov	16600	13700
16-Nov	16100	13800
17-Nov	15600	13800
18-Nov	15300	13700
19-Nov	15300	13800
20-Nov	15600	13800
21-Nov	15800	13600
22-Nov	15600	13600
23-Nov	15300	13500
24-Nov	15000	13500

Appendix 1. (Continued).

DATE	AUG-91 TO JUN-92 AVG	AUG-92 TO JUN-93 AVG
25-Nov	14900	13400
26-Nov	15900	12900
27-Nov	16700	12500
28-Nov	17000	12200
29-Nov	16900	12300
30-Nov	16400	12900
01-Dee	15900	13600
02-Dec	15500	13700
03-Dec	15200	13600
04-Dec	15500	13700
05-Dec	15700	12700
06-Dec	15900	11900
07-Dec	18000	11800
08-Dec	19500	12500
09-Dec	19000	12900
10-Dec	18100	13500
11-Dec	17600	13900
12-Dec	17000	14300
13-Dec	16600	14400
14-Dec	16700	14200
15-Dec	16100	13900
16-Dec	17300	13700
17-Dec	18300	13700
18-Dec	16500	13600
19-Dec	17200	13300
20-Dec	19500	13300
21-Dec	18200	13400
22-Dec	16500	13400
23-Dec	16600	13700
24-Dec	15900	13800
25-Dec	15200	14000
26-Dec	15200	13800
27-Dec	15400	13700
28-Dec	16600	13400
29-Dec	15800	13500
30-Dec	15000	14900
31-Dec	15500	14900
01-Jan	15200	15100
02-Jan	15900	13600
03-Jan	19900	15600
04-Jan	17100	17800
05-Jan	15900	15800
06-Jan	15300	14900
07-Jan	18000	14800
08-Jan	22200	14000
09-Jan	21800	13200
10-Jan	19800	13100
ll-Jan	18800	16200
12-Jan	16500	16000
13-Jan	15900	16900

Appendix 1. (Continued).

DATE	AUG-91 TO JUN-92 AVG	AUG-92 TO JUN-93 AVG
14-Jan	17900	17200
15-Jan	19600	14400
16-Jan	18100	14500
17-Jan	17300	14000
18-Jan	17300	18600
19-Jan	16400	17300
20-Jan	17600	15900
21-Jan	19600	19700
22-Jan	18100	18900
23-Jan	16300	20100
24-Jan	16700	17700
25-Jan	16600	20600
26-Jan	15100	17400
27-Jan	15800	19200
28-Jan	19800	18200
29-Jan	19900	19400
30-Jan	17000	18400
31-Jan	19200	20900
01-Feb	19100	20000
02-Feb	19100	22800
03-Feb	19100	19900
04-Feb	19100	17800
05-Feb	19100	17800
06-Feb	19100	16500
07-Feb	19100	15600
08-Feb	19100	15800
09-Feb	19100	18200
10-Feb	18300	15900
ll-Feb	17600	14800
12-Feb	17400	17700
13-Feb	18600	16000
14-Feb	16800	15900
15-Feb	16600	16100
16-Feb	16700	21300
17-Feb	16700	24000
18-Feb	17600	22600
19-Feb	18700	20700
20-Feb	20100	15600
21-Feb	26100	20100
22-Feb	26700	16900
23-Feb	26600	20800
24-Feb	25300	21700
25-Feb	25500	22100
26-Feb	25200	21900
27-Feb	25900	21200
28-Feb	24800	19200
01-Mar	25500	19900
02-Mar	23900	19200
03-Mar	26100	19600
04-Mar	24100	18500

Appendix 1. (Continued).

DATE	AUG-91 TO JUN-92	AVG	AUG-92 TO JUN-93	AVG
05-Mar	24500		15600	
06-Mar	25600		15400	
07-Mar	23600		16500	
08-Mar	23400		17800	
09-Mar	23700		17500	
10-Mar	23500		18300	
ll-Mar	24400		18400	
12-Mar	22600		20300	
13-Mar	22900		23300	
14-Mar	22000		22600	
15-Mar	20100		21800	
16-Mar	22200		20900	
17-Mar	25300		21200	
18-Mar	23800		25900	
19-Mar	24800		40500	
20-Mar	20200		53400	
21-Mar	19600		60200	
22-Mar	19200		58100	
23-Mar	20400		59000	
24-Mar	22100		67400	
25-Mar	18600		79700	
26-Mar	18400		78300	
27-Mar	18500		75200	
28-Mar	18600		72900	
29-Mar	18700		54400	
30-Mar	18700		57700	
31-Mar	18700		56000	
01-Apr	18800		50800	
02-Apr	19300		50600	
03-Apr	20100		54900	
04-Apr	21200		55100	
05-Apr	22000		67600	
06-Apr	21800		74700	
07-Apr	21100		59500	
08-Apr	20300		52000	
09-Apr	19800		51500	
10-Apr	20600		52400	
ll-Apr	22400		54400	
12-Apr	23200		50800	
13-Apr	24000		48000	
14-Apr	25500		46000	
15-Apr	25500		44100	
16-Apr	25200		42300	
17-Apr	25400		43100	
18-Apr	28000		43500	
19-Apr	29100		48100	
20-Apr	27800		42400	
21-Apr	26700		46800	
22-Apr	27700		43000	
23-Apr	28900		42500	

Appendix 1. (Continued).

DATE	AUG-91 TO JUN-92 AVG	AUG-92 TO JUN-93 AVG
24-Apr	25600	44200
25-Apr	24300	43900
26-Apr	24000	47400
27-Apr	25800	46700
28-Apr	31800	49000
29-Apr	29100	48100
30-Apr	32300	51200
01-May	40900	52500
02-May	47200	50100
03-May	45000	52200
04-May	44200	62000
05-May	44600	66400
06-May	42500	67800
07-May	37100	69500
08-May	39700	70500
09-May	**40900**	68300
10-May	40000	63600
11-May	36400	64600
12-May	33300	71700
13-May	30900	85800
14-May	28900	101000
15-May	28200	110000
16-May	27600	113000
17-May	27800	113000
18-May	27200	111000
19-May	27800	114000
20-May	29600	115000
21-May	30700	118000
22-May	28800	118000
23-May	26800	109000
24-May	26000	98200
25-May	25800	92200
26-May	26100	87500
27-May	27900	96500
28-May	28100	96600
29-May	25900	95300
30-May	24500	93500
31-May	23400	85300

Appendix 2. -Snake River main stem and tributary discharge data (1992-1993).

MONTH	YEAR	HELLS CANYON DAM	IMNAHA RIVER	SALMON RIVER	GRANDE RONDE RIVER	SNAKE RIVER AT (ANATONE, WA)
01-Aug	1992	6580	138	3410	569	10700
02-Aug	1992	6600	134	3330	540	10600
03-Aug	1992	6600	131	3240	505	10500
04-Aug	1992	6580	129	3120	473	10300
05-Aug	1992	6570	128	3020	444	10100
06-Aug	1992	6600	126	3930	431	9990
07-Aug	1992	6610	126	3860	424	9910
08-Aug	1992	6640	126	3830	419	9870
09-Aug	1992	6680	124	3820	410	9880
10-Aug	1992	6720	118	2790	399	9900
11-Aug	1992	6790	115	2740	396	9980
12-Aug	1992	6680	113	2690	395	9970
13-Aug	1992	6570	111	2630	384	9740
14-Aug	1992	6530	109	2560	375	9550
15-Aug	1992	6540	109	2520	374	9450
16-Aug	1992	6530	119	2530	368	9430
17-Aug	1992	6550	122	2620	384	9470
18-Aug	1992	6540	121	2720	398	9650
19-Aug	1992	6560	113	2720	403	9690
20-Aug	1992	6520	110	2650	391	9620
21-Aug	1992	6530	108	2570	393	9490
22-Aug	1992	6550	116	2510	747	9440
23-Aug	1992	6570	125	2580	526	9630
24-Aug	1992	6540	120	2610	527	9570
25-Aug	1992	6580	115	2640	498	9640
26-Aug	1992	6570	111	2620	489	9580
27-Aug	1992	6550	110	2600	468	9510
28-Aug	1992	6560	108	2610	451	9510
29-Aug	1992	6550	106	2560	436	9440
30-Aug	1992	6540	103	2510	425	9390
31-Aug	1992	6530	101	2470	415	9330
01-Sep	1992	6520	100	2440	416	9260
02-Sep	1992	6560	99	2430	410	9260

Appendix 2. (Continued).

MONTH	YEAR	HELLS CANYON DAM	IMNAHA RIVER	SALMON RIVER	GRANDE RONDE RIVER	SNAKE RIVER AT (ANATONE, WA)
03-Sep	1992	6530	98	2420	412	9270
04-Sep	1992	6540	100	2400	417	9220
05-Sep	1992	6540	104	2450	450	9230
06-Sep	1992	6530	105	2570	449	9310
07-Sep	1992	6520	105	2660	433	9410
08-Sep	1992	6560	105	2710	431	9490
09-Sep	1992	6580	106	2750	448	9590
10-Sep	1992	6870	104	2740	442	9750
ll-Sep	1992	6540	102	2690	424	9850
12-Sep	1992	6610	103	2650	405	9490
13-Sep	1992	6900	103	2710	403	9640
14-Sep	1992	6900	103	2820	422	9980
15-Sep	1992	7110	103	2740	459	10100
16-Sep	1992	7420	103	2670	478	10500
17-Sep	1992	7480	100	2650	465	10800
18-Sep	1992	7410	99	2590	436	10500
19-Sep	1992	7400	98	2530	446	10500
20-Sep	1992	7290	97	2490	448	10300
21-Sep	1992	7740	97	2500	467	10400
22-Sep	1992	7430	96	2530	457	11000
23-Sep	1992	7080	94	2520	446	10200
24-Sep	1992	7130	105	2530	505	10100
25-Sep	1992	7220	115	2820	806	10400
26-Sep	1992	7260	113	3320	747	11000
27-Sep	1992	7440	106	3380	658	11400
28-Sep	1992	7690	104	3220	637	11600
29-Sep	1992	7720	100	3140	620	11800
30-Sep	1992	10400	98	3000	600	12200
01-Oct	1992	11362	97	3051	577	13650
02-Oct	1992	11604	97	2959	562	15100
03-Oct	1992	10595	102	2938	574	14700
04-Oct	1992	10548	127	3093	642	14200
05-Oct	1992	10369	112	3345	650	14300

Appendix 2. (Continued).

MONTH	YEAR	HELLS CANYON DAM	IMNAHA RIVER	SALMON RIVER	GRANDE RONDE RIVER	SNAKE RIVER AT (ANATONE, WA)
06-Oct	1992	10343	106	3689	630	14500
07-Oct	1992	10118	103	3593	620	14600
08-Oct	1992	9893	102	3455	612	14300
09-Oct	1992	9761	103	3381	604	14100
10-Oct	1992	9782	102	3404	593	14000
11-Oct	1992	10000	102	3393	593	14100
12-Oct	1992	10179	101	3391	584	14200
13-Oct	1992	10178	102	3366	602	14200
14-Oct	1992	10201	104	3438	608	14200
15-Oct	1992	10312	103	3410	617	14300
16-Oct	1992	10228	103	3340	608	14500
17-Oct	1992	10162	106	3323	603	14100
18-Oct	1992	10204	107	3328	590	14200
19-Oct	1992	10249	107	3310	581	14200
20-Oct	1992	10407	105	3313	573	14300
21-Oct	1992	10438	106	3331	575	14400
22-Oct	1992	10286	108	3316	588	14400
23-Oct	1992	9865	108	3297	604	14100
24-Oct	1992	9114	106	3282	589	13400
25-Oct	1992	9225	106	3257	573	13200
26-Oct	1992	9203	106	3257	573	13200
27-Oct	1992	9244	106	3234	574	13200
28-Oct	1992	9283	107	3225	584	13200
29-Oct	1992	9206	117	3264	605	13300
30-Oct	1992	9199	155	3438	664	13300
31-Oct	1992	9160	156	3765	745	13700
01-Nov	1992	9147	139	3384	858	14000
02-Nov	1992	9102	153	4015	966	14300
03-Nov	1992	9099	141	4058	929	14400
04-Nov	1992	9144	129	3967	850	14200
05-Nov	1992	9101	127	3836	884	14100
06-Nov	1992	9101	123	3724	857	14000
07-Nov	1992	9209	123	3666	864	13900

Appendix 2. (Continued).

MONTH	YEAR	HELLS CANYON DAM	IMNAHA RIVER	SALMON RIVER	GRANDE RONDE RIVER	SNAKE RIVER AT (ANATONE, WA)
08-Nov	1992	9110	130	3725	959	13900
09-Nov	1992	9137	128	3794	990	14100
10-Nov	1992	9081	119	3793	925	14100
11-Nov	1992	9080	105	3660	868	13900
12-Nov	1992	9128	123	3447	836	13700
13-Nov	1992	9107	122	3363	833	13600
14-Nov	1992	9079	118	3561	818	13500
15-Nov	1992	9109	118	3646	821	13700
16-Nov	1992	9075	119	3632	817	13800
17-Nov	1992	9075	119	3596	798	13800
18-Nov	1992	9109	120	3589	804	13700
19-Nov	1992	9112	118	3602	812	13800
20-Nov	1992	9092	119	3566	800	13800
21-Nov	1992	9060	113	3442	807	13600
22-Nov	1992	9091	109	3414	833	13600
23-Nov	1992	9098	122	3409	816	13500
24-Nov	1992	9111	89	3496	776	13500
25-Nov	1992	9090	46	3220	693	13400
26-Nov	1992	9101	58	3702	667	12900
27-Nov	1992	9096	85	2236	669	12500
28-Nov	1992	9063	123	3090	751	12200
29-Nov	1992	9078	124	3736	731	12300
30-Nov	1992	9164	107	3269	696	12900
01-Dee	1992	9334	103	3359	722	13600
02-Dec	1992	9326	112	3254	711	13700
03-Dec	1992	9396	109	3334	679	13600
04-Dec	1992	9249	59	3146	656	13700
05-Dec	1992	9177	44	2311	550	12700
06-Dec	1992	9179	28	2055	518	11900
07-Dec	1992	9186	130	1964	828	11800
08-Dec	1992	9138	129	2379	1220	12500
09-Dec	1992	9146	114	3043	1050	12900
10-Dec	1992	9170	114	3354	1010	13500

Appendix 2. (Continued).

MONTH	YEAR	HELLS CANYON DAM	IMNAHA RIVER	SALMON RIVER	GRANDE RONDE RIVER	SNAKE RIVER AT (ANATONE, WA)
11-Dec	1992	9176	112	3703	1060	13900
12-Dec	1992	9196	107	3723	1040	14300
13-Dec	1992	9159	103	3613	965	14400
14-Dec	1992	9134	97	2412	888	14200
15-Dec	1992	9067	103	3267	888	13900
16-Dec	1992	9072	88	3245	a33	13700
17-Dec	1992	9119	82	3182	843	13700
18-Dec	1992	9083	92	3040	830	13600
19-Dec	1992	9084	69	2916	822	13300
20-Dec	1992	9110	85	2848	882	13300
21-Dec	1992	9175	112	2874	842	13400
22-Dec	1992	9156	114	3047	853	13400
23-Dec	1992	9159	112	3307	888	13700
24-Dec	1992	9138	105	3480	927	13800
25-Dec	1992	9099	85	3505	899	14000
26-Dec	1992	9052	89	3332	907	13800
27-Dec	1992	9130	11	3077	872	13700
28-Dec	1992	9118	104	2970	878	13400
29-Dec	1992	10510	106	3178	891	13500
30-Dec	1992	9330	102	3293	870	14900
31-Dec	1992	11808	99	3344	872	14900
01-Jan	1993	9058	97	3360	918	15100
02-Jan	1993	9942	76	3213	898	13600
03-Jan	1993	13324	66	3066	879	15600
04-Jan	1993	12852	73	3108	867	17800
05-Jan	1993	11233	93	2870	853	15800
06-Jan	1993	10814	95	2797	832	14900
07-Jan	1993	10836	64	2548	800	14800
08-Jan	1993	10361	98	2556	a34	14000
09-Jan	1993	9231	139	2557	856	13200
10-Jan	1993	11643	176	2554	989	13100
ll-Jan	1993	11934	195	2821	968	16200
12-Jan	1993	12825	187	3028	957	16000

Appendix 2. (Continued).

MONTH	YEAR	HELLS CANYON DAM	IMNAHA RIVER	SALMON RIVER	GRANDE RONDE RIVER	SNAKE RIVER AT (ANATONE, WA)
13-Jan	1993	13680	195	2897	977	16900
14-Jan	1993	10468	526	3044	1010	17200
15-Jan	1993	9981	1560	3214	1070	14400
16-Jan	1993	8768	1240	3086	1070	14500
17-Jan	1993	11126	709	3174	953	14000
18-Jan	1993	13571	378	3204	958	18600
19-Jan	1993	10677	336	3175	916	17300
20-Jan	1993	14579	163	3178	987	15900
21-Jan	1993	13877	140	3093	1150	19700
22-Jan	1993	15237	140	3348	1220	18900
23-Jan	1993	14741	119	3383	1080	20100
24-Jan	1993	14551	118	3388	1050	17700
25-Jan	1993	13627	144	3344	976	20600
26-Jan	1993	14428	136	3203	933	17400
27-Jan	1993	14867	127	3189	930	19200
28-Jan	1993	13962	121	3192	934	18200
29-Jan	1993	14915	129	3131	938	19400
30-Jan	1993	15090	124	3165	919	la400
31-Jan	1993	16944	106	3166	942	20900
01-Feb	1993	18646	115	3008	925	20000
02-Feb	1993	15857	116	2802	890	22800
03-Feb	1993	15395	123	2733	916	19900
04-Feb	1993	13168	142	2813	931	17800
05-Feb	1993	14814	136	2832	954	17800
06-Feb	1993	11909	141	2899	959	16500
07-Feb	1993	9269	146	2950	938	15600
08-Feb	1993	14950	142	2986	950	15800
09-Feb	1993	12304	149	3186	975	18200
10-Feb	1993	9463	155	3279	1030	15900
ll-Feb	1993	11681	156	3498	1140	14800
12-Feb	1993	11043	155	3503	1230	17700
13-Feb	1993	10737	153	3547	1280	16000
14-Feb	1993	9188	151	3561	1300	15900

Appendix 2. (Continued).

MONTH	YEAR	HELLS CANYON DAM	IMNAHA RIVER	SALMON RIVER	GRANDE RONDE RIVER	SNAKE RIVER AT (ANATONE, WA)
15-Feb	1993	13816	150	3487	1320	16100
16-Feb	1993	18126	108	3192	1240	21300
17-Feb	1993	18212	80	2809	1150	24000
18-Feb	1993	18603	170	2618	1150	22600
19-Feb	1993	12983	186	2661	1140	20700
20-Feb	1993	15268	178	2980	1150	15600
21-Feb	1993	9777	157	3261	1180	20100
22-Feb	1993	15060	150	3348	1120	16900
23-Feb	1993	16063	147	3191	1070	20800
24-Feb	1993	16351	150	3240	1060	21700
25-Feb	1993	17748	134	3210	974	22100
26-Feb	1993	19654	97	3118	912	21900
27-Feb	1993	14713	115	3086	889	21200
28-Feb	1993	14027	144	3027	928	19200
01-Mar	1993	15917	136	2905	921	19900
02-Mar	1993	16522	146	2887	919	19200
03-Mar	1993	12276	142	3085	927	19600
04-Mar	1993	14235	139	3188	938	18500
05-Mar	1993	11155	145	3331	969	15600
06-Mar	1993	10774	148	3408	1070	15400
07-Mar	1993	11504	162	3534	1300	16500
08-Mar	1993	12053	193	3814	1740	17800
09-Mar	1993	10985	209	4146	2160	17500
10-Mar	1993	11249	215	4406	2430	la300
ll-Mar	1993	11072	223	4475	2630	18400
12-Mar	1993	14747	217	4392	2530	20300
13-Mar	1993	17107	218	4177	2310	23300
14-Mar	1993	13733	209	4040	2260	22600
15-Mar	1993	12137	210	4099	3350	21800
16-Mar	1993	10088	219	4302	5350	20900
17-Mar	1993	11798	226	4541	4910	21200
18-Mar	1993	17359	276	4741	7100	25900
19-Mar	1993	28323	372	5222	9660	40500

Appendix 2. (Continued).

MONTH	YEAR	HELLS CANYON DAM	IMNAHA RIVER	SALMON RIVER	GRANDE RONDE RIVER	SNAKE RIVER AT (ANATONE, WA)
20-Mar	1993	37124	485	6021	10200	53400
21-Mar	1993	38156	554	6746	10200	60200
22-Mar	1993	37030	525	6565	9290	58100
23-Mar	1993	37229	596	6400	10400	59000
24-Mar	1993	48647	1070	7081	13200	67400
25-Mar	1993	54801	1130	8313	11800	79700
26-Mar	1993	53571	976	8700	10200	78300
27-Mar	1993	51437	932	9292	9080	75200
28-Mar	1993	47479	939	9985	8610	72900
29-Mar	1993	38182	914	10033	8050	54400
30-Mar	1993	36395	796	9574	7220	57700
31-Mar	1993	34932	706	9024	6650	56000
01-Apr	1993	30027	761	8589	6800	50800
02-Apr	1993	32345	a32	8798	7350	50600
03-Apr	1993	32183	845	8969	8370	54900
04-Apr	1993	31798	1070	9387	11100	55100
05-Apr	1993	48516	918	10859	9830	67600
06-Apr	1993	46232	810	10696	8480	74700
07-Apr	1993	34263	785	9796	7830	59500
08-Apr	1993	30419	791	8981	7610	52000
09-Apr	1993	30457	791	8836	8170	51500
10-Apr	1993	32530	791	9201	8120	52400
ll-Apr	1993	31016	791	9071	8030	54400
12-Apr	1993	32252	791	8587	7340	50800
13-Apr	1993	31810	791	7980	6800	48000
14-Apr	1993	27646	791	7556	6480	46000
15-Apr	1993	24994	791	7312	6180	44100
16-Apr	1993	27317	791	7204	5950	42300
17-Apr	1993	24670	791	7199	6010	43100
18-Apr	1993	27693	791	7728	6530	43500
19-Apr	1993	26637	796	a325	6330	48100
20-Apr	1993	25976	821	8080	6010	42400
21-Apr	1993	28301	821	7835	5820	46800

Appendix 2. (Continued).

MONTH	YEAR	HELLS CANYON DAM	IMNAHA RIVER	SALMON RIVER	GRANDE RONDE RIVER	SNAKE RIVER AT (ANATONE, WA)
22-Apr	1993	22943	821	7874	6050	43000
23-Apr	1993	24601	846	8302	6330	42500
24-Apr	1993	25943	844	8780	6210	44200
25-Apr	1993	25590	a57	11183	6270	43900
26-Apr	1993	26958	1000	9134	7080	47400
27-Apr	1993	26664	977	9365	6930	46700
28-Apr	1993	27892	914	9167	6600	49000
29-Apr	1993	28033	934	9116	6740	48100
30-Apr	1993	28615	1110	10301	8550	51200
01-May	1993	26417	1160	11346	8800	52500
02-May	1993	23371	1250	11720	9000	50100
03-May	1993	26486	1580	12828	9370	52200
04-May	1993	27664	2250	15859	11300	62000
05-May	1993	29790	2130	17021	11100	66400
06-May	1993	30660	2310	16859	11200	67800
07-May	1993	31718	1875	17931	11200	69500
08-May	1993	33227	1875	17964	10800	70500
09-May	1993	31934	1875	16861	9810	68300
10-May	1993	30568	la75	16086	9270	63600
ll-May	1993	30593	1875	17944	9950	64600
12-May	1993	30818	1875	24316	11900	71700
13-May	1993	35024	1875	35216	13700	85800
14-May	1993	35320	1875	45249	14900	101000
15-May	1993	35984	1875	53010	14600	110000
16-May	1993	35957	1875	56264	13400	113000
17-May	1993	35999	1875	56457	12500	113000
la-May	1993	37195	1875	55523	11700	111000
19-May	1993	38848	1875	56450	11600	114000
20-May	1993	37576	1875	60159	11800	115000
21-May	1993	37487	1875	64176	11200	118000
22-May	1993	36310	la75	63250	9720	118000
23-May	1993	33033	1875	56532	8500	109000
24-May	1993	33601	1875	50012	7560	98200

Appendix 2. (Continued).

MONTH	YEAR	HELLS CANYON DAM	IMNAHA RIVER	SALMON RIVER	GRANDE RONDE RIVER	SNAKE RIVER AT (ANATONE, WA)
25-May	1993	29528	1875	47085	7080	92200
26-May	1993	27164	1875	51419	7580	87500
27-May	1993	29531	1875	54377	7320	96500
28 -May	1993	29441	1875	54593	7140	96600
29-May	1993	29890	1875	53637	6700	95300
30 -May	1993	30365	1875	49892	6040	93500
31-May	1993	27062	1875	46329	5800	85300
01-Jun	1993	25225	1875	46947	6180	83400
02-Jun	1993	23439	1875	46037	6440	82700
03-Jun	1993	26892	1875	43493	6630	80500
04-Jun	1993	29972	la75	41508	6650	84400

Appendix 3. -Snake River water temperatures at RK 347 and RK 265 (1991-1993).

MONTH	RK 265 (1991-92)	RK 265 (1992-93)	RK 347 (1991-92)	RK 347 (1992-93)
18-Aug	22.6	22.5	20.6	21
19-Aug	22.9	22.5	20.8	21.1
20-Aug	22.8	22.5	20.7	21.1
21-Aug	22.6	22.2	20.8	20.8
22-Aug	22.7	21.2	20.7	20.3
23-Aug	22.7	20	20.7	19.9
24-Aug	22.1	19.4	20.6	19.9
25-Aug	21.8	19.3	20.6	20
26-Aug	21	19.5	20.5	20.3
27-Aug	20.8	19.9	20.7	20.5
28-Aug	20.8	20.3	20.6	20.8
29-Aug	20.9	20.2	21	20.3
30-Aug	21.3	20	21.2	19.9
31-Aug	21.6	19.8	21.2	19.8
01-Sep	21.4	20	20.8	20.1
02-Sep	20.7	20.2	20.5	20.4
03-Sep	20.6	20.3	20.5	20.2
04-Sep	20.6	20	20.7	20
05-Sep	20.8	19.4	21	19.7
06-Sep	21.1	18.7	21.1	19.4
07-Sep	21.3	18.2	21.3	19.4
08-Sep	21.1	18.2	20.9	19.3
09-Sep	20.5	18.4	20.8	19.7
10-Sep	20.6	18.6	21	19.7
ll-Sep	20.6	19.2	21	19.9
12-Sep	20.8	19	21	19.7
13-Sep	20.6	18.3	20.8	19.1
14-Sep	20	17.4	20.7	18.8
15-Sep	20	17	20.5	18.7
16-Sep	20	17.3	20.7	18.9
17-Sep	20.1	17.7	20.8	19.2
18-Sep	20.2	17.7	20.8	18.7
19-Sep	20.2	17.7	20.8	la.9
20-Sep	20	18	20.6	19
21-Sep	19.5	18.5	20.2	19.3
22-Sep	18.8	18.9	19.9	19.4
23-Sep	18.5	19.2	20	19.3
24-Sep	19	18.7	20	18.8
25-Sep	19.1	17.9	20	18.6
26-Sep	19.3	17.4	20	la.6
27-Sep	19.6	17.4	20	18.8
28-Sep	19.3	17.4	19.9	18.7
29-Sep	19.2	17.6	19.9	18.8
30-Sep	19.1	17.8	19.9	18.9
01-Oct	19.1	18.3	19.8	18.9
02-Oct	la.9	18.2	19.7	18.8
03-Oct	18.6	18.1	19.2	18.6
04-Oct	17.5	17.8	18.9	18.6

Appendix 3. (Continued).

MONTH	RK 265 (1991-92)	RK 265 (1992-93)	RK 347 (1991-92)	RK 347 (1992-93)
05-Oct	17.4	17.5	la.8	18.3
06-Oct	17.2	17	la.7	18.2
07-Oct	17.1	16.5	18.7	17.8
08-Oct	17.2	16.2	18.4	17.7
09-Oct	17	16.1	18.2	17.8
10-Oct	16.9	16.2	18.2	17.7
11-Oct	16.7	16.2	18.1	17.7
12-Oct	16.6	16.1	18	17.6
13-Oct	16.4	16	17.9	17.5
14-Oct	16.2	15.6	17.8	17
15-Oct	16.3	14.8	17.8	16.7
16-Oct	16.4	14.4	17.7	16.5
17-Oct	15.7	14.6	17.3	16.7
18-Oct	15	14.8	17	16.6
19-Oct	15	15	17	16.6
20-Oct	15	15.1	16.9	16.4
21-Oct	14.9	14.8	16.8	16.3
22-Oct	14.7	14.8	16.4	16.2
23-Oct	14.2	14.7	16.2	16
24-Oct	13.8	14.3	15.8	15.8
25-Oct	13.5	14	15.7	15.7
26-Oct	13.2	13.9	15.5	15.6
27-Oct	12.9	13.7	15.3	15.5
28-Oct	12.4	13.4	14.9	15.3
29-Oct	11.8	13.3	14.5	15.3
30-Oct	11.2	13.2	14.1	15
31-Oct	11	13	14	14.9
01-Nov	11	12.9	13.9	14.8
02-Nov	10.6	12.5	13.3	14.5
03-Nov	9.9	12.2	13.1	14.3
04-Nov	10	11.7	12.8	13.9
05-Nov	10.2	11.7	12.8	13.9
06-Nov	10.1	11.5	12.7	13.7
07-Nov	9.8	11.5	12.6	13.5
08-Nov	9.4	11.4	12.6	13.4
09-Nov	9.7	11.1	12.5	13.1
10-Nov	10	10.6	12.2	12.8
ll-Nov	9.8	10.3	12.1	12.4
12-Nov	9.9	10.2	12.1	12.5
13-Nov	10.1	10.3	12	12.5
14-Nov	9.8	10.3	11.7	12.3
15-Nov	9.3	10.1	11.4	12.1
16-Nov	8.9	9.9	11.2	12
17-Nov	9	9.9	11.2	11.9
18-Nov	9.1	9.9	11.1	11.8
19-Nov	9.1	9.6	10.8	11.4
20-Nov	9	9.2	10.7	11.3
21-Nov	8.6	8.9	10.4	11
22-Nov	8.3	8.7	10	11

Appendix 3. (Continued).

MONTH	RK 265 (1991-92)	RK 265 (1992-93)	RK 347 (1991-92)	RK 347 (1992-93)
23-Nov	7.7	8.5	9.7	10.9
24-Nov	7.6	8.2	9.7	10.4
25-Nov	7.7	7.5	9.6	10.1
26-Nov	7.5	7.2	9.5	9.8
27-Nov	7.5	7.1	9.3	9.5
28-Nov	7.1	7.2	9	9.6
29-Nov	6.7	7.2	8.8	9.3
30-Nov	6.3	7.1	a.5	8.7
01-Dee	6.2	6.4	8.4	8.6
02-Dec	6.4	6.2	8.3	8.5
03-Dec	6.6	6	8.4	8
04-Dec	6.8	5.5	8.3	7.7
05-Dec	6.7	5	8.1	7.3
06-Dec	6.8	4.9	8.1	6.9
07-Dec	6.5	4.9	7.9	7
08-Dec	6.4	5	7.6	7.1
09-Dec	6	5.2	7.5	7.2
10-Dec	5.7	5.3	7.6	7.2
11-Dec	5.7	5.1	7.3	7
12-Dec	6	4.9	7.3	6.8
13-Dec	5.6	4.9	7.1	6.5
14-Dec	5.3	4.9	6.8	6.4
15-Dec	4.8	4.9	6.7	6.4
16-Dec	4.6	4.6	6.7	6.3
17-Dec	5	4.6	6.6	6.2
18-Dec	4.9	4.3	6.5	6.2
19-Dec	5.2	4.1	6.5	5.8
20-Dec	5	4.1	6.3	5.7
21-Dec	4.9	4.3	6	6
22-Dec	4.8	4.6	6.2	6
23-Dec	4.6	4.9	6	6
24-Dec	4.7	4.9	5.9	5.9
25-Dec	4.4	4.5	5.9	5.5
26-Dec	4.2	4.3	5.9	5.3
27-Dec	4.3	4.2	5.9	5.5
28-Dec	4.5	4.4	5.7	5.3
29-Dec	4.5	4.5	5.7	5.3
30-Dec	4.5	4.4	5.7	5.1
31-Dec	4.7	4.2	5.6	5
01-Jan	4.5	3.9	5.5	4.8
02-Jan	4.4	3.3	5.5	4.5
03-Jan	4.5	3.1	5.5	4.5
04-Jan	4.5	3.5	5.6	4.6
05-Jan	4.5	3.3	5.6	4.6
06-Jan	4.6	3.3	5.6	4.6
07-Jan	4.7	3.3	5.5	4.3
08-Jan	4.7	3.1	5.3	3.9
09-Jan	4.4	2.6	5.2	3.7
10-Jan	4.2	2.4	5.1	3.7

Appendix 3. (Continued).

MONTH	RK 265 (1991-92)	RK 265 (1992-93)	RK 347 (1991-92)	RK 347 (1992-93)
11-Jan	4.3	2.4	5	3.7
12-Jan	4.3	2.5	4.9	3.6
13-Jan	4.4	2.4	4.8	3.5
14-Jan	4.3	2.8	4.7	3.5
15-Jan	4.2	2.7	4.6	3.6
16-Jan	4.3	2.8	4.7	3.4
17-Jan	4.3	2.6	4.8	3.2
18-Jan	4.4	2.7	4.6	2.8
19-Jan	3.9	2.4	4.4	2.5
20-Jan	3.6	2.3	4.4	2.8
21-Jan	3.7	2.6	4.3	2.8
22-Jan	3.7	2.6	4.2	2.8
23-Jan	3.7	2.4	4.3	2.5
24-Jan	4.1	2.3	4.5	2.5
25-Jan	4.3	2.6	4.4	2.6
26-Jan	4.1	2.7	4.3	2.5
27-Jan	4	2.6	4.3	2.2
28-Jan	4.4	2.4	4.6	2.1
29-Jan	4.6	2.4	4.4	2.1
30-Jan	4.5	2.3	4.2	1.9
31-Jan	4.3	2.1	4.1	1.6
01-Feb	4.3	1.9	3.8	1.5
02-Feb	4.4	1.8	3.8	1.7
03-Feb	4.2	1.8	3.6	1.8
04-Feb	3.7	1.9	3.4	1.9
05-Feb	3.3	2	3.5	1.8
06-Feb	3.1	2.1	3.6	1.9
07-Feb	3.2	2.3	3.7	2
08-Feb	3.7	2.3	3.9	1.9
09-Feb	4	2.4	3.9	2
10-Feb	4.1	2.7	3.7	2.2
11-Feb	4.1	2.9	3.8	2.2
12-Feb	4.2	3	3.7	2.2
13-Feb	4.4	3.1	3.8	2.2
14-Feb	4.6	3.2	3.7	2.3
15-Feb	4.5	2.9	3.7	2.2
16-Feb	4.4	2.1	3.8	1.9
17-Feb	4.3	1.6	3.7	1.9
18-Feb	4.3	1.8	3.9	2.1
19-Feb	4.5	2	4.1	2.2
20-Feb	5	2.1	4.1	2.3
21-Feb	5.3	2.4	4	2.1
22-Feb	5.4	2.3	4.1	2.1
23-Feb	5.4	2.4	4.1	2.1
24-Feb	5.5	2.4	4.2	2.1
25-Feb	5.8	2.2	4.3	2.1
26-Feb	5.9	2.2	4.4	2.3
27-Feb	5.9	2.3	4.4	2.3
28-Feb	5.9	2.5	4.5	2.3

Appendix 3. (Continued).

MONTH	RK 265 (1991-92)	RK 265 (1992-93)	RK 347 (1991-92)	RK 347 (1992-93)
01-Mar	6	2.6	4.6	2.2
02-Mar	6.2	2.8	4.8	2.3
03-Mar	6.5	2.9	4.9	2.2
04-Mar	6.5	2.8	5	2.3
05-Mar	6.8	3.3	5.2	2.6
06-Mar	6.7	3.8	5.1	2.8
07-Mar	6.7	4.2	5.2	3
08-Mar	7	4.3	5.6	3
09-Mar	7.4	4.5	5.7	3.1
10-Mar	7.5	4.5	5.9	3.2
ll-Mar	7.5	4.3	6.3	3.2
12-Mar	7.6	4	6.6	3.1
13-Mar	7.8	4.1	6.8	3.4
14-Mar	8.1	4.6	6.9	3.5
15-Mar	8.4	4.8	7.1	3.7
16-Mar	8.8	5	7.4	3.9
17-Mar	9	5.4	7.5	4
18-Mar	8.6	5.8	7.4	4.1
19-Mar	a.4	5.7	7.4	4.1
20-Mar	8.3	5.6	7.2	4.2
21-Mar	8.4	5.6	7.5	4.5
22-Mar	8.6	5.9	7.6	4.6
23-Mar	8.8	6.1	7.9	4.7
24-Mar	9	6	8.3	4.7
25-Mar	9.2	5.8	a.5	4.8
26-Mar	9.4	6.3	8.7	5.6
27-Mar	9.7	6.9	8.7	6.2
28-Mar	9.6	7.4	8.8	6.5
29-Mar	9.3	7.6	8.7	6.9
30-Mar	9.2	7.8	8.6	7.2
31-Mar	9.4	8.1	a.9	7.5
01-Apr	10.2	8.4	9.3	7.6
02-Apr	10.8	8.6	9.5	7.9
03-Apr	11.2	8.8	9.7	8.2
04-Apr	11.5	8.5	10.1	a.2
05-Apr	11.5	8.3	10	8.3
06-Apr	11	8.5	9.7	8.4
07-Apr	10.5	9	9.5	8.6
08-Apr	9.8	9.2	9.6	8.7
09-Apr	9.5	9.2	9.9	8.8
10-Apr	9.5	8.9	10	9
ll-Apr	9.7	8.9	10.2	9.1
12-Apr	9.6	9	10.2	9.2
13-Apr	9.8	9.1	10.3	9.4
14 -Apr	10.4	9.6	10.7	9.6
15-Apr	11.1	9.6	10.8	9.4
16-Apr	11.7	9.5	10.8	9.5
17-Apr	11.8	10	10.9	9.6
18-Apr	11.8	10.1	11	9.8

Appendix 3. (Continued).

MONTH	RK 265 (1991-92)	RK 265 (1992-93)	RK 347 (1991-92)	RK 347 (1992-93)
19-Apr	11.4	10.2	10.8	10.1
20-Apr	11	10.3	10.8	10
21-Apr	11.3	10.4	11.2	10.1
22-Apr	11.3	10.3	11.2	10.1
23-Apr	10.8	10.4	11	10.5
24-Apr	10.8	10.9	11	10.5
25-Apr	11	11	11.5	10.5
26-Apr	11.5	11.1	11.8	10.5
27-Apr	12.1	10.9	11.8	10.7
28-Apr	12.4	10.8	11.7	10.9
29-Apr	12. a	11	11.8	11.1
30-Apr	13.3	11.1	12	11.3
01-May	13.3	11.1	11.9	11.3
02-May	12.5	11.4	11.7	11.4
03-May	12.2	11.2	12.1	11.4
04-May	12.6	10.6	12.6	11.4
05-May	12.9	10.6	12.6	11.7
06-May	13.1	11.2	12. a	11.6
07-May	13.6	10.8	13.2	11.6
08-May	14	10.9	13.5	11.7
09-May	13.8	11.3	13.4	11.9
10-May	12.9	12	13	12.2
ll-May	12.6	12.7	13.3	12.6
12-May	12.4	13.2	13.5	12.8
13-May	12.2	13.2	13.3	13.1
14-May	12.4	12.9	13.7	13.4
15-May	12.9	12.6	14.1	13.5
16-May	13.6	12.4	14.3	13.4
17-May	13.9	12.2	14.1	13.9
18-May	14.2	12.4	13.9	14.2
19-May	14.6	12.7	14.2	14.3
20-May	14.9	12.7	14.3	14.2
21-May	15.1	12.6	14	14.5
22-May	14.4	12.4	13.8	15
23-May	14.2	12.6	14.2	15.5
24-May	14.9	13	14.7	15.8
25-May	15.6	13.5	15	15.8
26-May	16.3	13.9	15.1	16
27-May	16.7	13.9	15	16
28-May	16.5	13.9	14.8	16
29-May	16.4	13.7	14.9	16.2
30-May	16.3	13.8	14.9	16.3
31-May	16.4	13.8	14.9	16.4
01-Jun	16.8	14	15	16.6
02-Jun	17.2	13.8	15.1	16.4
03-Jun	17.5	13.5	15.4	16.3
04-Jun	17.4	13.5	15	16.2

Appendix 4.-IFG4 data deck used to simulate water velocity and depth at cross section four of the RK 261 spawning site.

```
SITE RK 261 TRANSECT 4 FLOW 3: 08/28/92 - CALIBRATED FOR 5400 TO
20000 CFS
RUN FOR 92 REPORT USING IFG4 W/ GAGE FLOW OF 9700 CFS  SZF =
948.20
IOC       11001000001001000001000
QARD 5400
QARD 5900
QARD 6400
QARD 6900
QARD 7400
QARD 7900
QARD 8400
QARD 8900
QARD 9400
QARD 9700
QARD10400
QARD10900
QARD11400
QARD11800
QARD12400
QARD12900
QARD13400
QARD14000
QARD14300
QARD14900
QARD15400
QARD15700
QARD16200
QARD16900
QARD17400
QARD17900
QARD18400
QARD18900
QARD19500
QARD19900
XSEC  2270   1000.00 1.0     948.2   0.00062
      2270   0.0970.5 29.0961.5 50.0958.5
84.0957.0122.0954.6132.0953.7

2270143.0954.5164.0957.2192.0957.8234.0956.3281.0954.3304.0953.2

2270329.0952.8344.0952.4358.0951.4386.0950.8416.0949.5453.0948.2

2270468.0946.8487.0944.6503.0942.3511.0940.6526.0940.0538.0938.5

2270545.0938.0561.0938.0569.0937.2578.0935.7583.0936.2596.0936.4

2270602.0937.5618.0940.3629.0945.4637.0947.8645.0950.8668.0950.7
      2270686.0952.4697.0953.1715.0954.3735.0957.4748.0962.1
NS    2270       0.0       7.6       7.6       5.6       6.50.08
6.5
```

```
NS      2270        6.5         6.5         5.6         5.60.08     5.60.08
5.6
NS      22700.025   6.50.025    6.5         6.5         6.6         6.6
0.0
NS      2270        0.0         0.0         0.0         0.0         0.0
0.0
NS      2270        0.0         0.0         0.0         0.00.076    0.00.076
0.0
NS      2270        0.00.079    0.00.075    0.0         0.00.057    7.7
7.7
NS      2270        7.70.082    7.7         7.7         7.7         7.7
CAL1    2270     954.31   9700.0
VEL1    2270                                .0001
0.50
VEL1    2270 2.20 3.10 3.00 3.35 3.30 3.40 3.25 3.45 3.55 3.55 3.80
3.90
VEL1    2270 3.60 3.75 3.65 3.45 3.05 3.00 3.10 2.25 2.95 1.50 2.70
1.55
VEL1    2270 0.70 0.10
CAL2    2270     956.20    16000.0
VEL2    2270
VEL2    2270
VEL2    2270
VEL2    2270
CAL3    2270     961.94    43700.0
VEL3    2270
VEL3    2270
VEL3    2270
VEL3    2270
ENDJ
```

Appendix 5.-Data used in emigration rate analysis in 1992.

TAG FILE$	TAG_ID$	REL_KM	REL_DAT	OBS_DATE	TRV_TIME	REL_SZ	LN_SZ	RATE	MIGR_FLO	LN_FLO	MIGRTEMP	LN_MTEMP	REL_TEMP	LN_RTEMP
upc9~113.248	7F7D0E051E	248	33717	33764	46.7	66	4.1897	1.6	55.4	4.0146	14.5	2.6741	12	2.4849
WPC92120.G62	7F7D0E5D17	262	33724	33777	53.4	74	4.3041	1.7	48.6	3.8836	15.6	2.7473	14	2.6391
WPC92120.G48	7F7D0E5171	248	33724	33778	53.6	73	4.2905	1.4	48.1	3.8733	15.7	2.7537	14	2.6391
WPC92134.262	7F7D0E0048	262	33737	33785	47.9	89	4.4886	1.9	38.2	3.6428	17.2	2.8449	13	2.5649
uPc92134.254	7F7D0F0214	254	33737	33771	33.4	68	4.2195	2.4	45.6	3.8199	16.2	2.785	13	2.5649
WPC92135.282	7F7D0B3512	282	33738	33784	26.8	71	4.2627	4.1	49	3.8918	16.1	2.7788	14	2.6391
wpc92135.282	7F7D0E4C6B	282	33738	33771	32.7	74	4.3041	3.3	44.4	3.7932	16.3	2.7912	14	2.6391
WPC92140.282	7F7D0E1B13	282	33743	33778	27	70	4.2485	4	43.5	3.7728	16.7	2.8154	15	2.7081
WPC92140.282	7F7D0E5A63	282	33743	33782	38.5	69	4.2341	2.8	36.9	3.6082	17.4	2.8565	15	2.7081
WPC92141.229	7F7D100105	229	33744	33761	16.7	60	4.0943	3.4	49.5	3.902	16.4	2.7973	15	2.7081
WPC92141.B42	7F7D0F6730	242	33744	33806	61.6	63	4.1431	1.1	33.2	3.5025	18.5	2.9178	15	2.7081
WPC92141.A42	7F7D0B3449	242	33744	33781	37.6	88	4.4773	1.8	36.6	3.6	17.5	2.8622	15	2.7081
WPC92141.248	7F7D0F6451	248	33744	33792	47.7	60	4.0943	1.6	34.8	3.5496	17.9	2.8848	15	2.7081
WPC92142.B51	7F7D0E0F40	251	33745	33762	17	81	4.3944	4.6	49	3.8918	16.5	2.8034	14.5	2.6741
WPC92142.B51	7F7D08233C	251	33745	33771	25.7	75	4.3175	3	41.9	3.7353	16.8	2.8214	14.5	2.6741
WPC92147.A51	7F7D0E107A	251	33750	33775	25	70	4.2485	3.1	38	3.6376	17.1	2.8391	16	2.7726
WPC92147.A51	7F7D0B317D	251	33750	33788	29.3	67	4.2047	2.7	35.7	3.5752	17.5	2.8622	16	2.7726
WPC92148.282	7F7D0E146A	282	33751	33763	11.7	92	4.5218	9.3	47.7	3.8649	17	2.8332	16	2.7726
WPC92148.G62	7F7D0F2C73	262	33751	33778	26.4	78	4.3567	3.4	35.6	3.5723	17.3	2.8507	16	2.7726
WPC92148.G62	7F7D0E403E	262	33751	33770	19	78	4.3567	4.7	39.9	3.6864	17.2	2.8449	16	2.7726
WPC92148.282	7F7D0E0F4E	282	33751	33777	26	68	4.2195	4.2	35.6	3.5723	17.3	2.8507	16	2.7726
wPC92148.282	7F7D0B3149	282	33751	33785	34.4	70	4.2485	3.2	31.9	3.4626	18.2	2.9014	16	2.7726
WPC92148.G62	7F7D0D6266	262	33751	33784	32.5	73	4.2905	2.7	32.3	3.4751	18.1	2.8959	16	2.7726
WPC92148.G62	7F7D0E1066	262	33751	33772	20.7	a7	4.4659	4.3	38.3	3.6454	17	2.8332	16	2.7726
WPC92149.B42	7F7D0E1F30	242	33752	33761	8.8	92	4.5218	7.8	46.4	3.8373	17	2.8332	17	2.8332
WPC92153.G62	7F7D0F4577	262	33756	33778	21.3	88	4.4773	4.2	33	3.4965	17.4	2.8565	17.5	2.8622
WPC92153.G62	7F7D0E0131	262	33756	33778	22.1	88	4.4773	4	32.4	3.4782	17.6	2.8679	17.5	2.8622
WPC92154.B42	7F7D0F6E5D	242	33757	33772	15.6	95	4.5539	4.4	34.4	3.5381	17.1	2.8391	17.5	2.8622
WPC92154.G50	7F7D11250A	250	33757	33768	11	a7	4.4659	7	38.8	3.6584	17.6	2.8679	17.5	2.8622
WPC92154.G50	7F7D10160B	250	33757	33774	16.7	a7	4.4659	4.6	33.9	3.5234	17.1	2.8391	17.5	2.8622
WPC92156.A51	7F7D0D5303	251	33759	33783	24.3	86	4.4543	3.2	27.8	3.325	18.4	2.9124	16	2.7726

Appendix 6. -Total number of incidental fish caught by beach seine in McNary Reservoir and the Hanford Reach of the Columbia River, Washington, 1992.

Common Name	Scientific Name	Total Catch	
		McNary	Hanford
American shad	*Alosa sapidissima*	406	0
Black crappie	*Pomoxis nigromaculatus*	1	1
Bluegill	*Lepomis macrochirus*	18	1
Bridgelip sucker	*Catostomus columbianus*	1	0
Coho salmon	*Oncorhynchus kisutch*	1	0
Sculpins	*Cottidae*	111	2
Crappie	*Pomoxis spp.*	4	0
Carp	*Cyprinus carpio*	35	4
Minnows	*Cyprinid spp.*	94	42
Largemouth bass	*Micropterus salmoides*	411	22
Largescale sucker	*Catostomus macrocheilus*	23	15
Bass	*Micropterus spp.*	3	0
Mountain whitefish	*Prosopium williamsoni*	44	2
Peamouth	*Mylocheilus caurinus*	117	378
Pumpkinseed	*Lepomis gibbosus*	20	2
Redside shiner	*Richardsonius balteatus*	1	899
Spring chinook	*Oncorhynchus tshawytscha*	13	3
Smallmouth bass	*Micropterus dolomieui*	73	25
Sunfish	*Lepomis spp.*	6	0
Northern squawfish	*Ptychocheilus oregonensis*	59	233
Threespine stickleback	*Gasterosteus aculeatus*	30	2
Rainbow trout	*Oncorhynchus mykiss*	1	0
Suckers	*Catostomus spp.*	2507	86
Sand roller	*Percopsis transmontana*	1	0
Yellow perch	*Perca flavescens*	513	0
Unidentified		425	0

Appendix 7.—Mean catch/seine haul (CPUE) of subyearling chinook salmon caught by beach seine during one week sampling intervals in McNary Reservoir and the Hanford Reach of the Columbia River, Washington and in the Snake River, Idaho, Oregon, and Washington, 1992.

Week Beginning With	McNary Reservoir Mean CPUE	Hanford Reach Mean CPUE	Snake River Mean CPUE
4/20			56
4/27			78
5/4	335		159
5/11	682		114
5/18		41	82
5/25	126	153	35
6/1	58	47	19
6/8			10
6/15	12	25	
6/22	15	a	
6/29			
7/6	1	1	

Appendix 8.—Mean fork length (FL) and standard deviation (SD) of subyearling chinook salmon caught by beach seine during one week sampling intervals in McNary Reservoir and the Hanford Reach of the Columbia River, Washington and in the Snake River, Idaho, Oregon, and Washington, 1992.

Week Beginning With	McNary Reservoir FL	McNary Reservoir SD	Hanford Reach FL	Hanford Reach SD	Snake River FL	Snake River SD
4/20					46.1	8.4
4/27					49.6	9.7
5/4	49.3	6.2			51.4	8.5
5/11	51.4	8.4			58.9	10.0
5/18			46.9	5.4	62.6	10.1
5/25	56.0	a.3	54.1	6.2	69.8	12.3
6/1	63.4	9.5	58.8	8.8	79.0	10.7
6/8					86.9	9.6
6/15	77.3	10.8	73.1	9.4		
6/22	84.2	9.2	75.2	8.9		
6/29						
7/6	89.6	9.3	88.5	4.8		

Appendix 9.-Summary of the number of subyearling chinook salmon marked with coded wire tags and brands or considered not suitable for marking at McNary Dam during 1992.

	MARKED					8 HOUR DELAYED MORTALITY AND TAG LOSS				UNMARKABLE				
Date	CWT Code	Brand	Marked & Bypassed	Held & Trans.	Total Mark.	#Morts	%Mort	#Lost Tags	%Tag Loss	Prev. 3randed	Desc.	Under-Size	Other Unmark.	Total Unmark.
Jun 16	29-52	LAK1	4,398	100	4,498	0	0.0	0	0.0	2	85		79	
Jun 17	29-52	LAK2	3.742	100	3,842	0	0.0	0	0.0	0	68	16	66	182 177
Jun 18	29-52	LAK3	3,627	100	3,727	0	0.0	0	0.0	4	86	3	125	218 140
Jun 19	29-54	LAK4	4,911	100	5,011	3	0.0	0	0.0					
Jun 20	29-54	RAK1	3.410	100	3,510		3.0	0	0.0	11	52	0	94	154
Jun 21	29-54	RAK2	2.938	100	3,038	0	0.0	1	1.0	14	1049	2	1578	273 138
Jun 22	29-53	RAK3	4,838		4,938	0	0.0	0	0.0					
Jun 23	29-53	RAK4	3,589	100	3,689	0	0.0	0	0.0	7		1		
Jun 24	29-53	LATX1	3,642	105	3,724		0.0	0	0.0	12	132 132	0	125 109	253
	Subtotal		35,095	905	36,000	3	0.3	1	0.1	44	795	55	892	1,800
Jul 2	29-51	LATX3	3 423	100	3,523	1	1.0	0	0.0	39	79	1	110	229
Jul 3	29-51	RATX1	4,842	100	4,942	0	0.0	0	0.0	60	87	0	52	
Jul 4	29-51	RATX3	3,449	100	3,549	1	1.0	0	0.0	71	61	0	52	199 184
Jul 5	29-50	LATC1	4,667	100	4,767	0	0.0	0	0.0	50		0		
Jul 6	29-50	LATC3	3,876	100	3,976	0	0.0	0	0.0	104	18	0	159	243 181
Jul 7	29-50	RATC1	3,243	100	3,343	0	0.0	0	0.0	62	22	0	55	149
Jul 8	29-49	RATC3	2,634	100	2,734	1	1.0	0	0.0	48	125	3	440	125
Jul 9	29-49	LATI1	5,307	100	5,407	3	3.0	0	0.0	52				
Jul 10	29-49	LATI3	2,365	100	2,465	0	0.0	0	0.0	20	40	0	101	620 161
Jul 11	29-49	RAT11	1,260	100	1,360	0	0.0	0	0.0	12	19	0	66	97
	Subtotal		35,052	1000	36,052	6	0.6	1	0.1	518	563	4	1,103	2,188
										93	73	0		
Jul 17	29-48	RAT13	6,353	100	6,453	2	2.0	10	10	49	117	0	245 162	411 338
Jul 18	29-48	LATY1	5,033	100	5.133	0	0.0	0	0.0					
Jul 19	29-46	LATY3	1,458	50	1.508	2	40	1	2.0	23	34	0	94	151
Jul 20	29-46	RATY1	1,441	50	1,491	3	6:0	0	0.0	16	31	0	114	161
Jul 21	29-46	RATY3	910	50	960	0	0.0	1	2.0	12	18	0	81	111
Jul 22	29-46	LA9C1	1,166	50	1.216	2	0.0	1	2.0	4	38			134
Jul 23	29-46	LA9C3	2,970	50	3,020	0	4.0	0	0.0	12	58	1	91	
Jul 24	29-46	RA9C1	2,443	50	2,493		0.0	1	2.0	23	67	1	174	245 265
Jul 25	29-46	RA9C3	1,378	50	1,428	1	2.0	1	2:o	14	61	1		
Jul 26	29-47	LATL1	2,256	50	2,306	0	0.0	0	0.0	14	82	0	83	237 218
Jul 27	29-47	LATL3	1,089	50	1,139	0	0.0	0	0.0	28	34 62	0	177	267 131
Jul 28	29-47	RATL1	1,869	75	1,919	0	0.0	0	0.0					
Jul 29	29-47	RATL3	3,274		3,349	1	1.3	0	0.0	37		0		
Jul 30	29-47	LATU1	3,463	70	3,533	0	0.0	0	0.0	43	105 116	3	267 298	409 460
	Subtotal		35,041	1.050	36,091	22	2.1	0	0.0	159	2,353	14	2,410	4,936

SUMMARY	MARKED			18 HOUR DELAYED MORTALITY AND TAG LOSS				UNMARKABLE				
	Marked & Bypassed	Held & Trans.	Total Mark.	#Morts	%Mort	#Lost Tags	%Tag Loss	Prev. Branded	Desc	Under-Size	Other Unmark.	Total Unmark.
TOTAL	105,250	2,750	108.000	20	0.7	16	0.6	960	2,254	66	4.236	8.924